Chair of Travel Behaviour
School of Engineering and Design
Technical University of Munich

The Impacts of the Environmental and Psychological Factors on Pedestrians' Perceived Safety

A Study Carried out in Munich

Md Asiful Alam

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Supervised by
Dr. Ana Tsui Moreno Chou
Chair of Travel Behaviour

Submitted by
Md Asiful Alam
03752469

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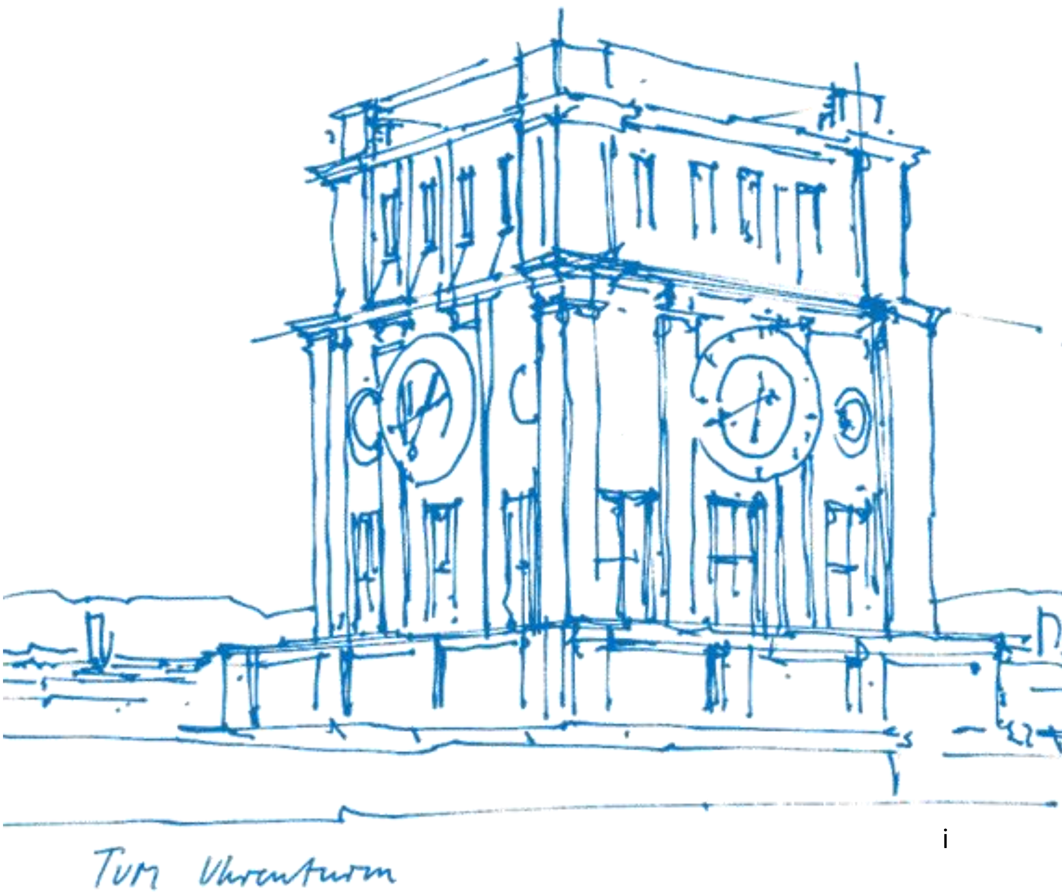

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Abstract

This study examines the complex interplay between environmental and personal factors in shaping pedestrians' perceived safety in Munich, a city renowned for its walkability. Study areas were selected taking five years of accident data and synthetic travel data into account, complemented by site inspection. Pedestrians' opinions were collected through one interception and one online survey. Key findings indicate major influences of sidewalk quality, crosswalk availability and traffic conditions on safety perceptions. Frequent walkers were found to have higher safety perceptions, while negative past experiences were found to have a diminishing effect on perceived safety. The impact of individuals' origins was significant on how they perceive an urban environment. Interestingly, Munich locals reported lower safety perceptions than the others, possibly due to higher baseline expectations. The study emphasizes identifying location-specific issues and user needs before planning any intervention or modification of the environment. Recommended measures include prioritizing infrastructure enhancements, traffic calming measures, and community engagement to encourage active mobility and sustainable urban development.

Keywords:

Pedestrian Safety, Road Safety, Perceived Safety, Walkability, Munich

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I would love to express my gratitude to all the strangers who were kind enough to participate in the surveys. I am grateful to my family, my friends; especially the wonderful people I live with, for being patient with me, for their moral support and encouragement. Their positivity kept me motivated and focused. Lastly, I want to acknowledge everyone who contributed in their own ways, offering support, insights, or by simply being there when I needed.

Technical University of Munich – Professor of Travel Behavior

Prof. Dr.-Ing. Rolf Moeckel
Arcisstraße 21, 80333 München, www.mos.ed.tum.de/tb/startseite/

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Topic: **A study on the impacts of walking infrastructures and traffic behavior on the pedestrians' perception of safety in the city of Munich.**

Pedestrian safety is an important aspect of planning urban mobility and public health. Munich, being known as a city with high walkability with extensive pedestrian infrastructures and facilities (Leasca, 2024), still is far from the Vision Zero targets. Some of the most accident-prone locations lie within the most commuted to or through areas (Unfallatlas, 2024). Understanding how pedestrians perceive the safety of walking in those areas can provide important insights into how the walkability of the Bavarian capital can be enhanced (Marisa & Fuad , 2023).

The research questions I am willing to answer are:

- How does the pedestrians' perception of safety vary among residents at the accident-prone areas in Munich?
- How do static factors, like walking infrastructures, and dynamic factors, like vehicle speed or volume, influence pedestrians' sense of safety and their willingness to walk?
- Are the most accident-prone areas (according to the statistics) really the ones which are perceived unsafe by the pedestrians?

This study will attempt to draw a comparison between residents' safety perceptions about different areas of the city and on-ground accident statistics of those areas. This comparison will provide an important insight into whether accidents concentrate at the locations which are perceived unsafe by the residents or elsewhere.

The thesis will consist of a literature review from the previous studies carried out on pedestrians' safety and perceived safety, a methodology to collect pedestrians' perception based on an online survey, a summary of the data collected through survey and from other sources (e.g. OpenStreetMap, Unfallatlas, etc.), an analysis showing how the collected data relates to or define the safety perception of the pedestrians, and finally the discussion summarizing the outcomes.

The student will present intermediate results to the mentor Ana Tsui Moreno Chou (Research Associate, Professorship of Travel Behavior, Technical University of Munich) in the fifth, tenth, 15th, and 20th weeks.

The student must hold a 20-minute presentation with subsequent discussion at most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis cannot be evaluated.

Dr. Ana Tsui Moreno Chou

Student's signature

Prof. Dr.-Ing. Rolf Moeckel

Arcisstraße 21, 80333 München, www.mos.ed.tum.de/tb/startseite/

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Abbreviations/Glossary

Usage of abbreviations has been kept limited in this report. However, some widely used German terminologies may need to be explained for non-German readers.

Straße – In Germany, street names end with the word “Straße”, such as “Leopoldstraße”. The literal translation of the word “Straße” is “Street”. Therefore, any word ending with “Straße” usually represents a street name. For example, “Leopoldstraße” means “Leopold Street”.

München- “München” is the German name for the city of Munich.

Hauptbahnhof/Hbf - The term “Hauptbahnhof” (Hbf in short) means “Central Train Station”. Therefore, “München Hbf” means “Munich Central Train Station”.

U-Bahn - In Germany, metro trains are called “U-Bahn”, which stands for “Untergrundbahn”. The literal translation of the word is “Underground Train”.

After a spontaneous hiking trip on a summer weekend, we decided to wrap up the evening with an equally spontaneous dinner at a restaurant not so far from the station. While walking to the restaurant, someone casually remarked, "I think, I'm not a big fan of this area". Not every day do you hear someone complain about Munich, "Why? What's so wrong with it?" I casually asked. "He's not wrong, you know? Cars, motorbikes, bikes, everything behave so strangely here; always give me anxiety which I'm sure I can live without. Also, it's always so crowded here." someone else replied while carefully allowing a biker ride past him on the sidewalk. The comment sparked a discussion. Some agreed, while others countered, "Maybe, you just need to be a little more alert here? Why is that so hard? I don't see anything wrong here".

As someone who generally finds Munich to be a perfectly safe city for walking, I stayed quiet, listening. The first person doubled down, asking, "Why do I have to stay constantly alert? Why can't I just walk peacefully while bikers and drivers just follow the rules and be civil?" Another chimed in while we waited for the signal to cross the street: "I get why you're concerned, but I think the area is quite safe. It's just these dark congested sidewalks and indistinguishable bike paths which make everything confusing.".

The light turned green, a bicycle coming from the other side of the street braked sharply to avoid crashing into a blue sedan taking a sharp right turn. "See? Why is everyone in a rush here? What if that biker hadn't stopped in time?" The group fell silent, collectively acknowledging that while Munich is a heaven for pedestrians compared to most cities in the world, some areas may feel noticeably less safe to some pedestrians than others regardless of however safe they really are, and the other way around.

1. Introduction

One important takeaway from the story above is that community narratives about a city, or certain parts of the city, sometimes create a lasting perception of safety or danger. While objective safety of a city can be measured using quantifiable data and metrics, an individual's subjective opinion on safety can be complex to explain. Due to individual differences, social and environmental contexts, these opinions may and do differ widely from person to person (Traunmueller et al., 2016). For instance, the safety perception of elderly individuals in a city or a neighborhood may be significantly different from the perceptions of the younger individuals. Past studies indicate that the factors necessary to feel safe in an environment are not exactly same for an elderly individual and someone younger (Wu et al., 2020). Beside age, people's safety perception can be significantly influenced by their gender and daily habits (Sundling & Jakobsson, 2023). Personal experiences, such as encountering or witnessing an accident, can also heighten sensitivity to specific types of dangers and can alter an individual's safety perception (Rod et al., 2023). For example, an individual with experience of getting hit by a bike on the sidewalk is likely to stay more alert about bikes while walking compared to someone who never encountered an incident like that. Aside from individual factors, it was found that cultural and social backgrounds can also shape our perceptions (Côté-Lussier et al., 2015). Depending on what they expect and how familiar they are with the area, environmental factors like the quality of lighting, available security measures, and the design of streets or neighborhoods are likely to impact how an individual perceives safety at a specific neighborhood (Kim et al., 2024). Therefore, the travel behavior of city residents across various demographics and socioeconomic groups is profoundly shaped by their perceptions of safety. Unsurprisingly, pedestrians are one of the most affected commuter groups, as their choices and movements are closely tied to how safe they feel navigating the urban landscape on foot (Sundling & Jakobsson, 2023).

1.1 Motivation

Walking is globally considered as an efficient and easily accessible form of exercise. It helps attain physical fitness, while also contributes to one's mental well-being (Matkovic et al., 2022). Walking increases physical activity level which helps in reducing adiposity. Aside from health benefits, studies show that walking-friendly neighborhoods generate better cohesion among the residents than the neighborhoods where walking experience is not as pleasant. Active mobility modes (e.g. walking, bicycles, etc.), social interactions and recreational activities were found to be important in building healthier communities (Roscoe et al., 2023). Hence, walkability is regarded as an essential element of sustainable urban design principles. However, mode choice in day-to-day commutes involves interplays of many factors and is a complicated process. Especially in urban settings, an individual's decision to use a specific transport mode is not always rationally explainable, which is no different for walking. An individual's decision to engage in walking as a mode of transport or recreation is heavily influenced by their perceived safety. When a neighborhood is generally perceived unsafe, it often keeps the residents away from choosing active mobility modes like walking or cycling.

Being widely recognized as one of the most pedestrian-friendly cities in the world, Munich is famous for its layout and extensive pedestrian-friendly infrastructure. The city's compact design also makes it ideal for exploring cultural landmarks like the English Garden and Viktualienmarkt on foot. With 86% of its population living within one kilometer of car-free spaces, Munich scored the fourth highest for safety when a study analyzed cities around the world to find out which ones offer the most walkable environment (Leasca, 2024). Recently initiatives are being taken which are focused on achieving climate neutrality by 2035 (Munich Climate Targets 2035 -

Between Wish and Reality, 2023). These initiatives include implementation of traffic calmed areas, redesigning intersections and improvement in crossing opportunities to enhance the safety of the pedestrians. The city council has also passed resolutions to extend pedestrian zones in various parts of the city, including the old town. One of the primary aim of these initiatives is to reduce motorized traffic and free up public space for pedestrians, while also encouraging community interactions (Weiss et al., 2023).

One important aspect to consider is the wide variation of pedestrian activity across different parts of Munich. The city encompasses a diverse range of environments, from bustling commercial districts and crowded tourist hotspots to lively neighborhoods filled with restaurants and cafes, as well as tranquil parks and quiet residential areas. This diversity creates distinct pedestrian experiences and influences safety perceptions in varying ways. Additionally, Munich is widely multicultural in nature due to the presence of international students and professionals from all over the world. According to a recent report, approximately 30% of the 1.59 million inhabitants of Munich have foreign citizenships coming from 180 different countries, making it one of the most popular German cities for foreign nationals (Munich Business, 2024). This multicultural nature also influences different perceptions of safety, as visitors and residents from countries with varying urban environments are likely to evaluate the walking environment of Munich differently.

1.2 Objective and Scope

A clear understanding of how the environmental and psychological factors impact pedestrians' perceived safety is essential in building an environment which will prioritize the needs of all pedestrians. Perceived safety not only shapes walking behavior, but it also plays an important role in improving social interaction and cohesion. Therefore, this study aims to:

1) Find out how perceived safety varies among pedestrians at the low-risk and high-risk areas in Munich.
2) Identify the key determinants which influence pedestrians' safety perceptions and provide recommendations on improving infrastructure and actions necessary to enhance overall pedestrian experience in a city.
3) Explore how safety perceptions of pedestrians can be influenced by the environment they grew up in and their experiences.
4) Assess if the areas perceived unsafe by the pedestrians are really unsafe by comparing them with the objective safety.

These insights will help the policymakers and urban planners to determine the interventions which will address the crucial factors impacting pedestrian safety perceptions. It will also assist in allocating resources more meticulously, so that planned improvements enhance both physical and perceived safety. Furthermore, an understanding of the psychological aspects involving pedestrians' origins and personal experience can help make the cities more inclusive, accessible and pedestrian-friendly.

1.3 Document Structure

This thesis report is structured as follows. Chapter 2 covers the relevant background literature which explored various aspects of pedestrian safety and safety perceptions, Chapter 3 discusses the data and methods used in this study. Chapter 4 describes the data collection and preparation process used by this study, based on which study areas were selected. Chapter 5 contains brief descriptions of the study areas according to the recorded accident data and own observations during physical inspection. Chapter 6 covers the results obtained from two surveys, while Chapter 7 summarizes and discusses the findings. Finally, Chapter 8 highlights the limitations of this study and recommendations for further research and policymaking, drawing a conclusion of the report.

2 Literature Review

2.1 Pedestrian and Walkability

In past studies, researchers tried to bridge connections between walking environments like physical infrastructures, safety measures and measures that create the perception of safety among pedestrians. The first terminology that needs to be defined here is, who are pedestrians and why they are different from other road users. According to the most recent definitions, the individuals who transport from and to different locations in a city by foot and require specially designated infrastructures for safe movement and accessible transportation, are called pedestrians. Pedestrians walk to connect various modes of transportation in order to navigate through urban environments (Valenzuela-Montes & Talavera-García, 2015). According to Van Schaick, J. & Van Der Spek, S. (2007), pedestrians are important components of urban design and planning processes, and their behaviors and choices influence factors like transportation systems, land use, and public spaces.

Pedestrian infrastructures are almost always separated from the vehicle traffic. They include the physical elements and facilities which are intended to provide safe and efficient pedestrian movement within urban environments, such as crosswalks, sidewalks, raised medians, signalization, and other features. These infrastructures ensures higher mobility and accessibility for the pedestrians (Mesfin & Denbi, 2022). The quality of pedestrian infrastructure makes a city more walkable, reduces private vehicles usage, and improves urban livability as a whole (Alhafez & Amalia, 2022). The term walkability refers to how friendly, accessible, pleasant and convenient a city is for pedestrians. Pedestrians have different needs than vehicle users while commuting. A transportation system needs to emphasize pedestrian comfort, safety, and accessibility to various destinations (Hollenstein & Bleisch, 2016). It promotes sustainable transportation, environmental development, and healthier lifestyles by encouraging walking as an active form of transport (Moayedi et al., 2013). A well-planned urban layout and street network with a high-quality walking infrastructure can make a city more pleasant and attractive to pedestrians, in one word – “Walkable”.

Although pedestrians tend to use separate infrastructures and walkways for commuting, traffic conditions can greatly influence walkability, especially in urban environments. High traffic volumes often increase risks for pedestrians. This phenomenon creates a perception of danger that discourages walking. Traffic volume refers to the number, behavior and types of vehicles on streets, roads, walkways, bike lanes, and public transit lines within a specific region (Gupta et al., 2022). Past studies show that the areas which generally have large traffic volume, usually lack pedestrian-friendly features, such as wide sidewalks and safe crosswalks. This makes the region unattractive to pedestrians (Parmar et al., 2024). On the other hand, urban designs which discourage high traffic movement, can make the environment safer and more pleasing for the pedestrians, thus make an area more walkable (Carvalho et al., 2023). Traffic calming measures (TCM) do that by physically modifying the road networks to reduce vehicle speeds, and thus enhance road safety (Badiger et al., 2023). These measures include speed bumps, speed humps, raised crosswalks, rumble strips, curb extensions, chicane, and refuge islands, among others. TCMs are implemented to force vehicles to reduce their speed, especially in areas which are prone to accidents. They change the street layouts or introduces obstacles that encourage vehicles to drive slower (Majer & Sołowczuk, 2023). When vertical and horizontal traffic calming devices are implemented which integrate well with the landscaping, they can effectively slow down vehicle speeds. Thus TCMs can create safer pedestrian environment (Cantisani et al., 2023).

2.2 Perceived Safety

While it is important to focus on the physical safety features, it is also important to emphasize how the city-dwellers perceive the walking environment in the city. That is where the factor called psychological safety, or perceived safety comes into play. The term was first coined by the psychologist and psychotherapist Carl Rogers in his seminal work "Client-Centered Therapy: Its Current Practice, Implications, and Theory" (Rogers, 1951). Although, he used the concept in a different arena of research. From a psychological point of view, it refers to an individual's subjective assessment of feeling secure and protected in a given environment. In transportation engineering, perceived safety can be defined as a general sense of feeling safe and risk-free. It refers to the confidence or belief that one can safely navigate through a place or situation without any fear or hesitation. (Zeng et al., 2022). According to previous research, perceived safety can be influenced by various factors, including the built environment, social interactions, physical activities, and past experiences (Noble, 2023).

Studies show that it is important to acquire an understanding of pedestrians' perceptions to improve safety measures. Reckless driving, light conditions and infrastructure design like junctions and pedestrian crossings are some of the factors which influence pedestrians' perceived safety (Wedagama et al., 2020). According to Rankavat & Tiwari (2020), while pedestrians' choice of crossing facilities depends on the relationship between actual and perceived accident risks, their travel behavior is influenced by their risk perception. Research indicates that pedestrians are more likely to engage in walking when they feel safe. Vozmediano et al. (2024) deducted that well-planned urban design elements like well-lit streets and visible surveillance encourage higher pedestrian activities by creating a heightened sense of safety.

2.3 Review of Past Studies on Perceived Safety

Researchers used myriads of methods to assess pedestrians' perceived safety in urban and rural areas. They often used both qualitative and quantitative approaches to identify the factors which influence how safe or unsafe pedestrians feel in different environments. Some of the data collection methods are as follows:

1) Surveys and Questionnaires:
    i. Surveys: Participants are asked about their perceptions of safety individually
    ii. Semantic Scales: Participants' feelings are rated between "safe" vs. "unsafe", or "Good" vs "Bad"
    iii. Likert Scales: Measuring perceived safety on a numerical scale (e.g., from 1 to 5 or 1 to 7)
2) Interviews and Focus Groups
    i. Focus Groups: Group discussions organized by researchers
    ii. In-depth Interviews: Individual interviews or discussion
3) Behavioral Observations
    i. Pedestrian Counts: Number of pedestrians in different areas can be viewed as an indirect measure of perceived safety. The assumption is that people tend to avoid areas which they do not find safe
    ii. Activity Mapping: Mapping where and when people choose to walk
4) Geospatial Analysis
    i. Geographical Information Systems (GIS): Analysis of spatial data, such as traffic accidents in order to identify accident hotspots where perceived safety might be low.
    ii. Heat Maps: To represent areas of high or low perceived safety, often derived from survey data or incident reports.

5) Psychophysiological Measures

   i. Heart Rate Monitoring: Used to assess physiological responses as pedestrians walk through different areas, with increased heart rates possibly indicating higher levels of stress or perceived danger.

   ii. Eye-Tracking: Pedestrians' gaze patterns are tracked to understand what elements of the environment they focus on when they feel unsafe.

6) Visual and Photographic Surveys

   i. Photo Elicitation: Participants are shown images of different urban environments and asked to rate their perceived safety. This can be combined with surveys or interviews to deepen the understanding.

   ii. Street View Analysis: Using tools like Google Street View to show participants specific locations and gather feedback on their perceptions of safety in those environments.

This study attempted to review some of the recent studies that shed light on the perceived pedestrians' safety (Table 1). These studies employed different methodologies, such as logistic and hierarchical linear regression analyses to assess risk dimensions which affect walking behavior of the pedestrians (Rod et al., 2023), ordinal logit regression to evaluate street characteristics that influence perception of safety among older pedestrians (Wu et al., 2020), and mathematical modeling to establish relations between perceived risk of crossing and actual crashes (Mukherjee & Mitra, 2022), etc. Data collection methods included surveys of pedestrian perceptions at multiple sites (Kim et al., 2024), semi-structured interviews with participants (Wu et al., 2020), and one study conducted a systematic review of existing literature (Sundling & Jakobsson, 2023), etc.

Study (Year)	Country	Methodology	Data Collection Method
1 (2024) (Kim et al., 2024)	S. Korea	Mediation effect analyses using a regression model to explore the relationships between various walking environmental factors and perceived safety	Surveys of pedestrians among 99 participants
2 (2023) (Sundling & Jakobsson, 2023)	Sweden	Systematic review of existing studies	63 relevant publications collected from academic databases. These included ScienceDirect, Scopus, PubMed, PsychInfo, and Google Scholar.
3 (2023) (Distefano & Leonardi, 2023)	Italy	Factors influencing pedestrians' willingness categorized into basic, performance, and excitement factors, and how their importance varies according to the age of the users	Exploration of the factors influencing pedestrians' willingness to walk using a questionnaire survey among 562 participants
4 (2023) (Andersson et al., 2023)	Sweden	Commuting pedestrians evaluated route environments using Active Commuting Route Environment Scale. Later, correlation, regression, and mediation analyses were conducted to study relationships.	294 commuting pedestrians in the inner urban area of Stockholm, Sweden were recruited via advertisements
5 (2022) (Mukherjee & Mitra, 2022)	India	Mathematical modeling to establish associations between perceived crossing difficulty and actual crashes	Road inventory survey to collect information on road infrastructures, spot-speed survey to estimate average speed at each intersection, video-graphic survey to estimate daily vehicle and pedestrian flows and a questionnaire survey among 6875 pedestrians to examine crossing difficulty.
6 (2022) (Zeng et al., 2022)	China	Statistical analysis to determine influence of built environment, social factors, physical activity.	Paper-based questionnaires were randomly distributed among the selected communities. 573 responses were received.
7 (2022) (Sung et al., 2022)	S. Korea	The research analyzed pedestrian-vehicle crash spots in Seoul to analyze the relationship between 5D measures and pedestrian crashes using negative binomial regression.	31,999 pedestrian-vehicle crashes in Seoul over three years
8 (2023) (Rod et al., 2023)	Australia	Linear regression analyses to assess risk dimensions	Cross-sectional online survey on perceived injury risk among 487 participants
9 (2021) (Rahm et al., 2021)	Sweden	Qualitative analysis of focus group discussions on walking in urban areas	Focus group discussions, structured walks, and qualitative analysis to gather data on the impact of urban greenery and street lighting on perceived safety
10 (2020) (Wu et al., 2020)	China	Ordinal logit regression to evaluate street characteristics influencing older pedestrians' perceived safety	Survey among 68 older participants using 39 simulated streetscape images and semi-structured, in-depth interviews of 8 of the participants
11 (2019) (Kemnitzer et al., 2019)	USA	Analyzed driver, pedestrian, and environmental factors for pedestrian injury	Observations of 1000 drivers and pedestrians' behaviors, as well as environmental characteristics that could impact pedestrian injury. National Electronic Injury Surveillance System (NEISS) dataset was utilized

12 (2015) (Harvey et al., 2015)	USA	Observational study on skeletal streetscape design effects on perceived safety	Surveys were conducted among 120 participants to gather data on perceived safety in relation to skeletal streetscape design
13 (2017) (Cox et al., 2017)	Australia	Statistical analysis assessed the impact of environmental features and driver characteristics	Surveys, interviews, and observations to gather information on risk and safety perception. Population sample size was 1,200 drivers
14 (2018) (Jaberolansar, 2018)	Malaysia	Space syntax analysis measured syntactical variables in urban environments. Factor analyses examined the impact of townscape factors on pedestrian safety.	400 questionnaires distributed among pedestrians in streets.
15 (2018) (Xu et al., 2018)	China	Structural equation modeling for analyzing pedestrian inconvenience, traffic safety climate, and pedestrian behavior	Surveys were conducted among 1000 pedestrians
16 (2016) (Traunmueller et al., 2016)	UK	Analysis of covariance applied to collected data to predict safety perception. Also, a qualitative study was conducted with 15 images to explore safety perceptions	Presenting images of pre-selected types of people overlaid on different urban backgrounds to 500 participants, who were asked to rate them in terms of safety perception and familiarity. 5452 safety ratings were collected
17 (2014) (Zhou et al., 2014)	S. Korea	Biofeedback equipment used to study pedestrians' behavior and safety perception	Biofeedback equipment was used for the study involving 36 participants while walking along sidewalks, cross signalized intersections, a pedestrian actuated signal, and an unsignalized mid-block crosswalk in their normal speeds and behaviors
18 (2014) (Evans-Cowley et al., 2014)	USA	Discrete choice models to analyze factors influencing safety perceptions based on visual surveys with Google Street View for intersection preferences	Visual surveys using Google Street View were conducted where 203 participants viewed paired slides of images of intersections on the Ohio State University campus
19 (2012) (Hazrati, 2012)	Malaysia	Observation survey to identify urban form characteristics	The study utilized observation surveys and questionnaires to collect data on pedestrian experiences and perceptions of walkability in Melaka's historical core

Table 1 Methodologies and data collection methods used by past studies

Factors identified across these studies which influence pedestrians’ safety perception include street characteristics (e.g., footpath width, traffic volume, and isolation), infrastructural deficiencies and high-speed traffic, and the psychological effects of urban environments, which necessitate both positively and negatively activating spaces. Overall, the findings of the 19 reviewed studies highlight the multifaceted nature of perceived safety, emphasizing the necessity of comprehensive urban planning to enhance pedestrian experiences. The influencing factors found in these studies can be grouped in 4 main categories; Accessibility and built environment, aesthetics and visibility, demographic and psychological factors, and finally, traffic conditions (Table 2).

Factors \ Studies (Year)	Sum	1 (2024)	2 (2023)	3 (2023)	4 (2023)	5 (2022)	6 (2022)	7 (2022)	8 (2023)	9 (2021)	10 (2020)	11 (2019)	12 (2015)	13 (2017)	14 (2018)	15 (2018)	16 (2016)	17 (2014)	18 (2014)	19 (2012)
Accessibility and Built Environment																				
Maintenance	7	x		x			x						x			x	x			x
Quality of Infrastructure	6	x	x				x				x					x				x
Urban Layout	9		x			x		x				x		x	x		x		x	x
Crossing Condition	7	x				x						x		x		x		x	x	
Sidewalk Presence and Width	7	x		x							x	x	x	x				x		
Navigation and Accessibility	6		x	x			x								x				x	x
Walking Comfort	3	x									x					x				
Aesthetics and Visibility																				
Light Condition	7		x	x						x		x	x				x			x
Greeneries	6		x	x	x		x			x			x							
Visual Prospect	4		x			x				x					x					
Traffic Conditions																				
Traffic Volume	10	x	x			x	x	x	x		x	x				x			x	
Traffic Speed	9	x	x		x	x	x		x		x	x				x				
Traffic Control and Calming Measures	4			x								x				x		x		
Traffic Noise	2				x													x		
Driver Characteristic	3											x		x		x				
Demographic and Psychological factors																				
Gender	5				x						x	x					x	x		
Age	6			x					x		x	x					x	x		
Past Experiences	2								x									x		
Physical Condition	2										x						x			
Individual Risk Perception	5								x					x	x		x	x		

Table 2 Influencing factors identified by past studies

From the review, it is evident that although there are many factors which influence perceived safety among the pedestrians, some of them have been identified as more crucial than the rest, such as traffic volume and speed, urban layout, social environment, sidewalk condition, infrastructure maintenance, light condition etc.

Studies show that risk perception can vary significantly from person to person, influenced by their past experiences and, in some cases, by personal disabilities. Experiences such as being involved in or witnessing traffic accidents can significantly impact their perceived safety in an urban environment, especially around the main streets (Rod et al., 2023). These experiences increase their awareness of risks and vulnerabilities, making them more concerned about safety. However, an opposite impact was observed by a study carried out Ngueutsa & Kouabenan (2017), which suggests that the Individuals who have been involved in more than three accidents or severe accidents tend to perceive road travel as less risky. The study also indicates that these individuals are more likely to engage in less safe behavior compared to those with fewer or less severe accidents, suggesting a diminished perception of risk. Aside from collisions, near-accident experiences can also impact an individual's perceived safety. Studies show that near accidents between pedestrians and cyclists are much more frequent than actual collisions, occurring about 50 times more often. These incidents typically take place at locations with shared pedestrians and bicycle paths, decreasing the involved individuals' sense of safety and willingness to walk (Mesimäki & Luoma, 2021). Conversely, another study suggests that repeated near-accidents can foster less cautious behavior, as individuals may interpret these experiences as evidence of their ability to avoid danger, equipping them with a false sense of invulnerability (Terum & Svartdal, 2019).

Additionally, experiences gathered from different cultural backgrounds can also play a role in shaping an individual's perception of safety (Côté-Lussier et al., 2015). Individuals from regions with less structured traffic systems are likely to adjust more quickly to similar environments. They are likely to have even higher safety perception in a regulated environment. On the contrary, individuals from the cities or regions with regulated traffic environments are likely to feel safer at similar environments, but their safety perception Is likely to drop at the urban environments with less regulated traffic.

3 Materials and Methods

3.1 Research Methodology

The approach of this study comprises a comprehensive examination of 5 years' pedestrians-related accident data (2018-2022) sourced from Unfallatlas (*Unfallatlas*, n.d.). The accident data was normalized based on the walking trips' origins obtained from Mito-Moped synthetic population data throughout different postal zones in Munich, followed by a spatial analysis to identify high-risk locations. Field investigation was conducted at seven selected locations to identify potential causes of crashes. After summarizing the findings from reviewed literatures and field investigation, two separate questionnaires were formulated for interceptive and online surveys. Finally, a statistical model was developed to identify the key factors that influence pedestrians' safety perception. Based on these insights, the study offers targeted recommendations to enhance safety perceptions for pedestrians. The research sequence is illustrated in Figure 1.

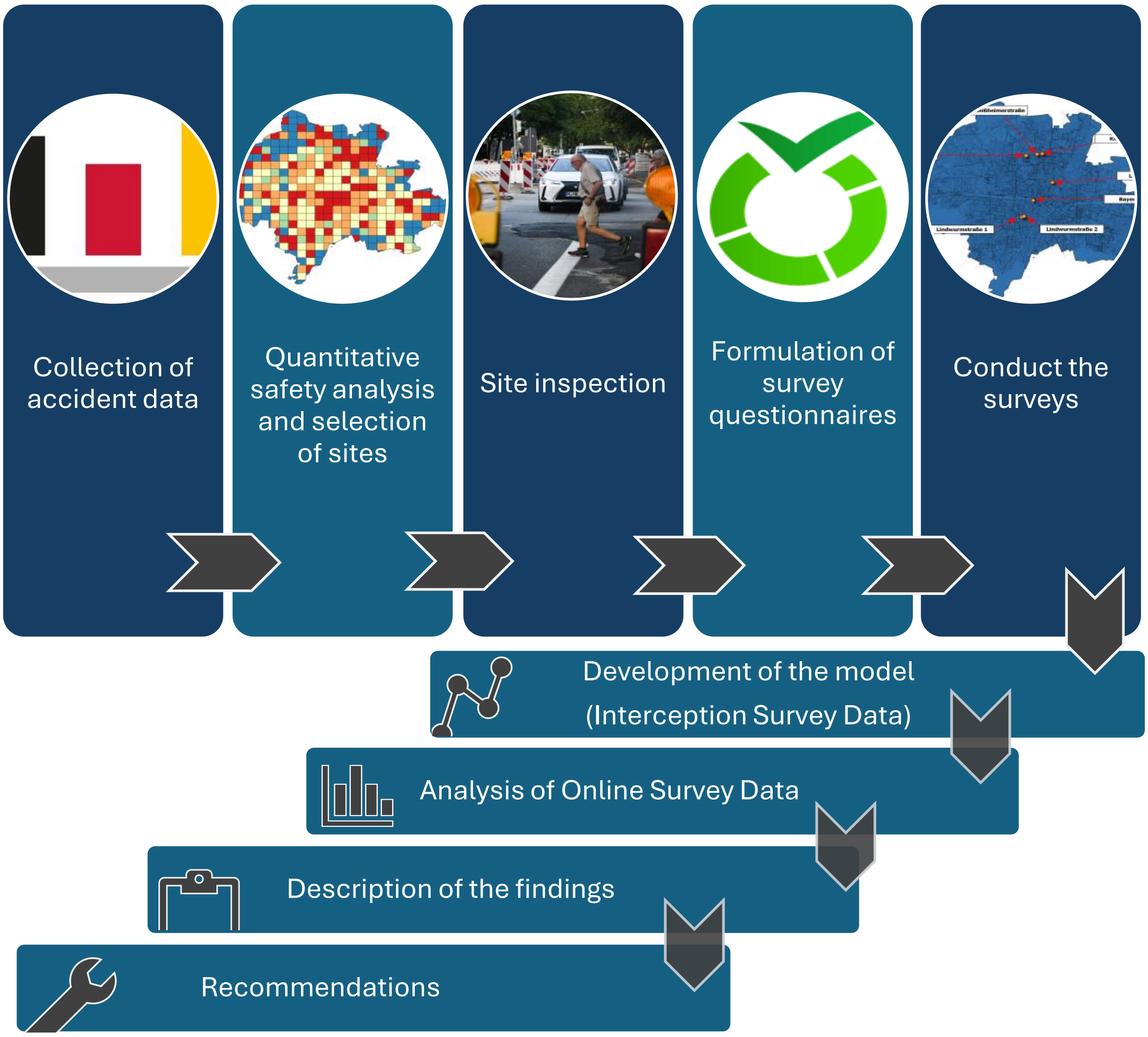

Figure 1 Research sequence

3.2 Quantitative Safety Analysis and Selection of Sites

For this research, past pedestrian related accident data were collected from Unfallatlas, and the locations of the accidents were plotted on the map of Munich using QGIS. Subsequently, Mito/MoPed Synthetic population data were used to normalize the accident throughout Munich based on pedestrian activity density and select moderate to high-risk intersections and street segments for this research.

3.3 Site Inspection

The sites selected for the investigation are different based on the street layouts, pedestrian activity volume, neighborhoods, proximity to activity hotspots, sidewalk types, etc. Consequently, the frequency and types of accidents recorded at these locations also exhibited notable differences. To ensure a comprehensive understanding of the context, preliminary inspections were conducted at each site before administering the survey. The accident data of each of these locations obtained from Unfallatlas were analyzed before the inspection. The primary goal of the inspection was to observe pedestrian behavior and their interactions with static (e.g., infrastructure, crosswalks, lighting) and dynamic elements (e.g., vehicular traffic, other pedestrians) of the environment. These observations provided important insights into the potential factors contributing to recorded accidents

3.4 Survey Data Collection Process

For this research, two separate surveys were conducted among the pedestrians and residents in Munich. The first survey was interceptive in nature, for which participants were approached in person at the selected locations and were requested to provide their feedback about that specific area. Responses were collected only from the people who said they live nearby or visit the area quite often. The second survey was conducted online, where participants were asked to provide their feedback about their walking experiences in Munich.

i. Interception Survey

The survey was carried out in the afternoon, between 16:00 and 18:00. Most office hours end during this time, and pedestrian activity is generally high due to all the homebound trips. This time was chosen to capture the experiences of pedestrians during a heavy traffic scenario. The environmental conditions were consistent across survey locations, ensuring that the participants' responses reflected the specific characteristics of the urban infrastructure, rather than variability in weather or lighting conditions.

For the interception survey, participants were chosen randomly. They were asked to provide their opinion about pedestrian safety in the area. Their opinions were collected also on the factors which likely influence the safety perception of pedestrians. Respondents were also encouraged to provide any open-ended feedback and suggestions about improvements that could make streets safer for pedestrians.

Survey Instrument

The interception survey consisted of nine questions, with a view to collecting the following variables for each participant:

Question Group 1:

In this question group, the participants were asked to provide basic information about themselves, which included their age, gender and walking habit.

- Gender: Coded as 0 (Prefer not to say), 1 (Male), 2 (Female), 3 (Diverse).
- Age Group: Coded from 1 to 6, with higher values indicating older age categories.
- Daily Amount of Walking: Coded from 1 to 4, with higher values indicating more frequent walking activities. This question was included based on the assumption that the people who walk more around the city every day, are more aware of the streetscapes, which helps them feel more confident about navigating traffic, recognizing potential hazards, and being more aware of their surroundings. Hence, their safety perception might be higher than the ones who walk significantly lesser.

Question Group 2:

In the second question group, a series of statements were presented to the participants where they were asked to indicate their level of agreement with each of them individually. 7-point Likert scale was used in this question, ranging from 1 (Strongly disagree) to 7 (Strongly agree), whereas 4 represents a neutral view ("I'm not sure"). Each of these statements was designed to assess one specific factor of pedestrian safety in the area. The factors were selected based on the review of past studies on pedestrian safety. They include:

- **Overall Perception of Safety**: Coded from 1 to 7, where higher values indicate a stronger perception of safety.
- **Sidewalk Condition**: Coded from 1 to 7, where higher values indicate better sidewalk conditions.

- **Traffic Conditions**: Coded from 1 to 7, where higher values represent better management of traffic conditions.
- **Crosswalk Availability**: Coded from 1 to 7, where higher values indicate better availability of crosswalks.
- **Crosswalk Timing**: Coded from 1 to 7, where higher values indicate better timing at crosswalks.
- **Lighting Conditions**: Coded from 1 to 7, where higher values indicate better street lighting conditions.

In the first question of this group, the participants provided their general opinion on the overall perception of safety, where they were provided with a simple statement that says

"I find this area pleasant and safe for walking."

In the next five questions, they responded about the individual factors, which offer deeper insights into how their perceptions of safety are influenced by varying levels of satisfaction or dissatisfaction with these factors. The statements in these questions were more elaborate, such as

"I think the vehicles' speed and density are not threatening for my safety when I walk in this area. I never feel the risk of getting hit by a vehicle."

Disagreement with a statement represents a lower score for that particular safety aspect, while agreeing to it indicates a higher score. The data collected was predominantly ordinal. Gender and age group were treated as categorical variables, with daily walking frequency also classified into ordinal categories. Each row in the dataset represents an individual respondent, with their respective responses across the measured factors.

ii. Online Survey

The online survey was aimed at gathering insights into the pedestrians’ overall safety perception in Munich. The link and the QR-code of the survey page were shared on Whatsapp groups of university students and Munich residents. Some of the participants spontaneously shared the survey link in Whatsapp groups of their respective workplaces.

The survey consisted of seven questions, where the first three questions were the same as the intercept survey. In addition, the survey collected the following responses from each participant:

- **Origin**: Coded as 0 (From Munich), 1 (From Germany, outside Munich), 2 (From Europe, outside Germany), 3 (From outside Europe)
- **Overall Safety Perception in Munich**: Coded from 1 to 10, where higher values indicate a stronger perception of safety.
- **Past Accident Experience**: The participants responded if they or anywhere close to them encountered any accident. They were allowed to choose multiple answers or to leave the question unanswered. The options provided for them were:
    - Had a near-collision experience
    - Was hit by a car
    - Someone close (a friend or family member) was hit by a car
    - Was hit by a bicycle at a crossing
    - Someone close (a friend or family member) was hit by a bicycle at a crossing
    - Was hit by a bicycle on the sidewalk
    - Someone close (a friend or family member) was hit by a bicycle on the sidewalk
- **Environmental Factors**: In this question, the respondents were provided with a list of 10 environmental factors and were asked to choose the ones they think influence their safety perceptions the most. The respondents were given the option to choose 3 to 5 factors from the list. The options provided were:
    - Sidewalk width, quality and maintenance
    - Sidewalk separation from cars
    - Sidewalk separation from bikes
    - Presence of other pedestrians
    - Pedestrian density
    - Traffic Condition
    - Availability and quality of the crosswalks
    - Presence of greenery
    - Light and visibility
    - Navigation and accessibility

The complete survey questionnaires can be found in **Appendix A** in this report.

4 Quantitative Safety Analysis and Selection of Sites

To comprehend the safety conditions in different parts of the city, this study investigated the past accident data obtained from Unfallatlas, which is a digital platform developed by Germany's Federal Statistical Office. The website provides interactive and comprehensive representation of the road traffic accidents data from the year 2016 onwards, which were reported by the police all over Germany (Figure 2).

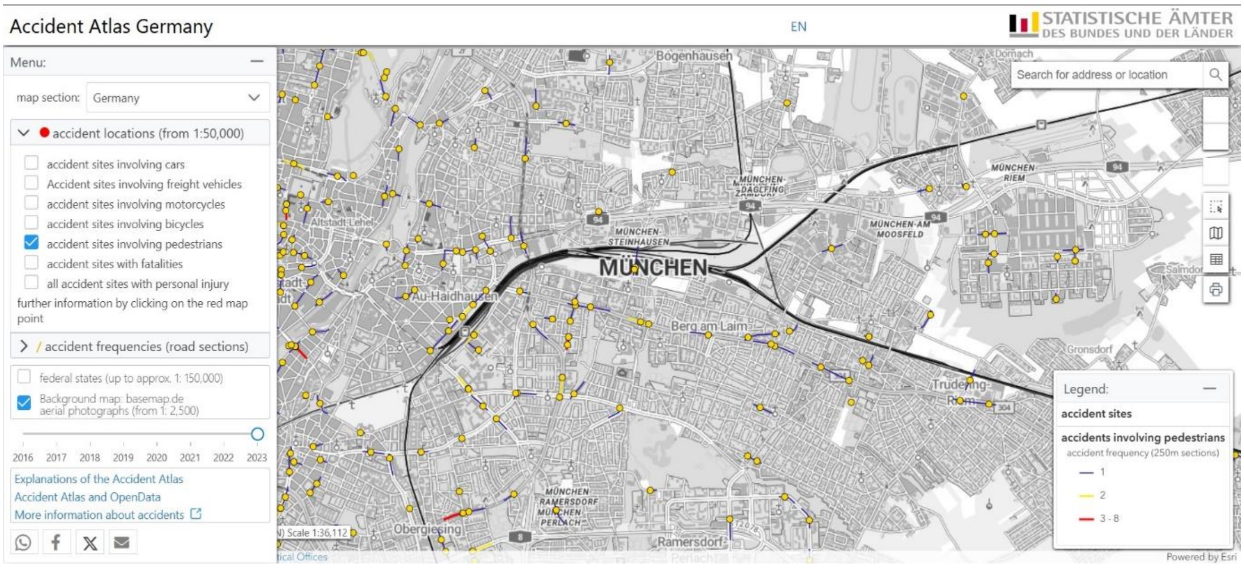

Figure 2 The user interface on Unfallatlas

As part of standard reporting procedure police document accident data which includes the necessary details such as the location, time, type and severity of accident, involved vehicles/parties etc. Other relevant factors like light and street surface condition during the accident are also

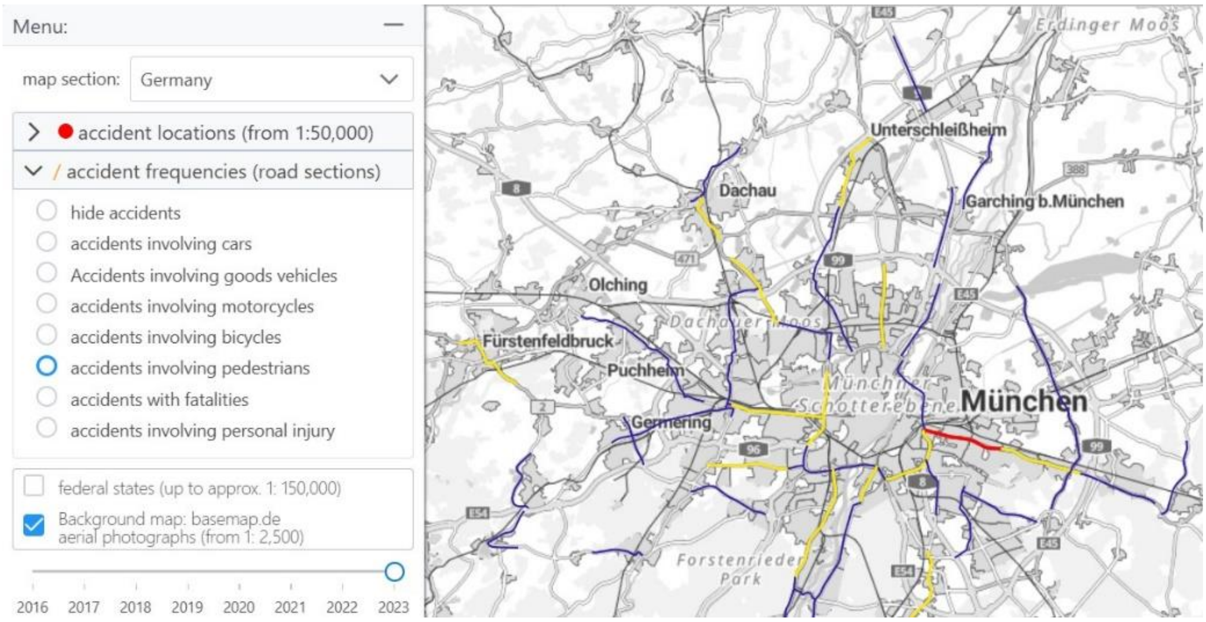

Figure 3 Filtering based on accident frequencies

included in the report. Yearly datasets of all reported accidents are available on the website. The integrated filtering options allow the users to find and sort the accidents based on certain parameters (Figure 3).

As the website offers a map-based visualization of the accident data, the users can zoom in on specific regions, cities, or even street segments to view individual accident details (Figure 4).

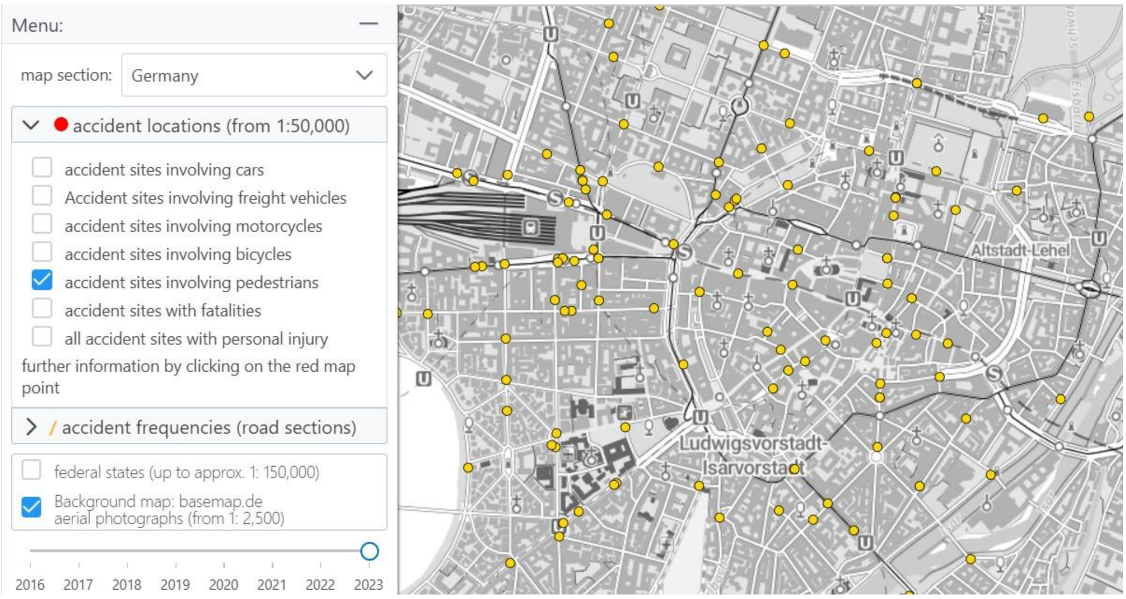

Figure 4 Filtering based on involved parties in the accidents

These datasets can be downloaded in common data formats, such as CSV or GeoJSON, which enables further analysis and their integration into external research projects. The available CSV files contain information like accident year, month, light condition, involved parties, severity, etc. for each reported accident, which are organized under 25 columns. Details of the data types contained by each column can be found in **Appendix B** on this paper.

For this research, 5 years' (2018-2022) accident data have been acquired from Unfallatlas, and later filtered to keep only the pedestrian-related crashes. The filtered dataset was imported to QGIS, and accidents were plotted on the map (Figure 5). To analyze the accident frequency or risk-level of different locations, it was also essential to take the city dwellers' travel data into consideration. Hence, the Mito/MoPed synthetic population data have been used as the reference to analyze the pedestrians' walking behavior in Munich (Q. Zhang et al., 2024). Based on the density of origin points of walking trips and the accident frequency, investigation sites were selected.

Mito/MoPed synthetic population data is a hybrid modeling framework which was designed to simulate pedestrian travel trend in Munich. This model combines MITO (an agent-based transport model) and MoPed (a pedestrian demand model) and was found to provide a much more precise and accurate representation of pedestrian mobility trend than the previous transport models used for Munich (Q. Zhang et al., 2024). This framework does not contain real mobility data, but a simulated dataset replicating realistic travel behavior based on demographic and spatial inputs. It captures various aspects of pedestrian movement, such as walk share, trip length distribution, etc.

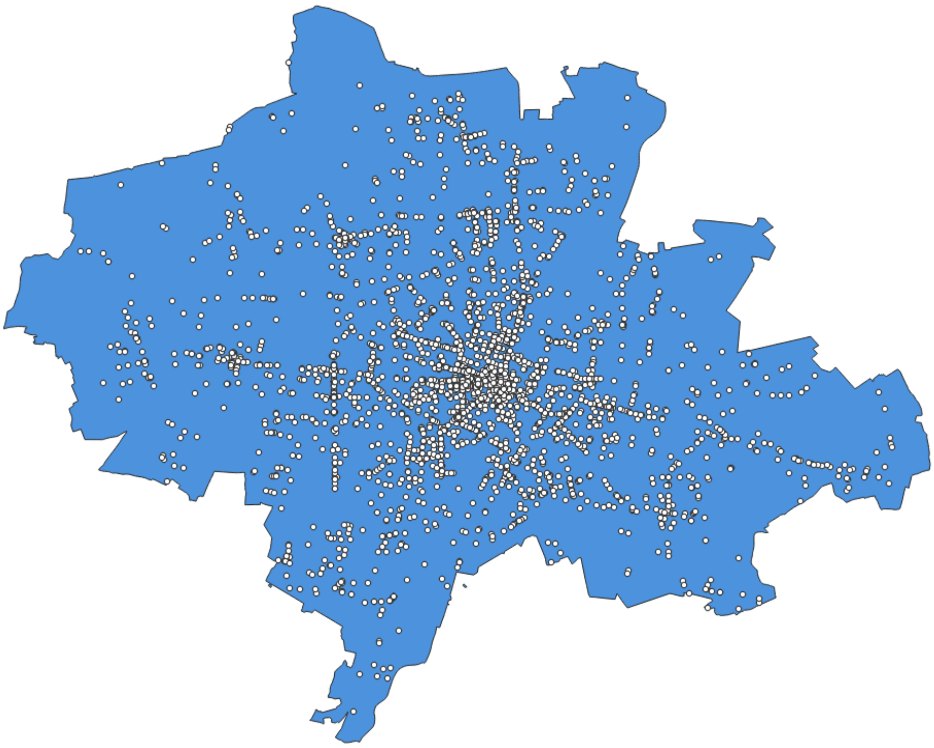

Figure 5 Locations of pedestrian related accidents in Munich (2018-2022)

According to this dataset, approximately 862000 walking trips of different purposes and lengths are generated in Munich throughout each weekday. To reduce the processing time of QGIS, only 263303 trips which take place from 0800 to 1000 hrs. in the morning and 1600 to 1800 hrs. in the afternoon, were taken into consideration. This filtration was done based on the hypothesis that majority of the regular/routine trips take place during morning and early evening peak hours (Vallée et al., 2021). The trips' origination points were plotted on the map in QGIS.

For the analysis, it was necessary to compare the accident frequencies among different areas in Munich. Initially, the comparison was made among different postal zones in Munich (Figure 6). However, it seemed unbalanced considering that the postal zones are not uniformly sized. Postal zones located towards the outskirts of Munich are significantly bigger than the postal zones located around the city center.

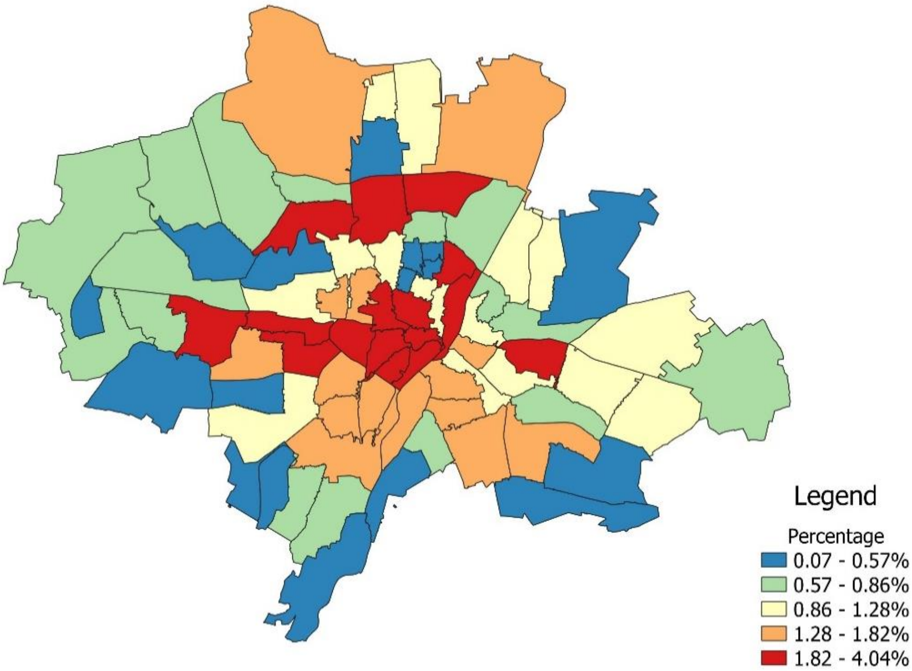

Figure 6 Percentage of total number of pedestrian related accidents in different postal zones of Munich

To solve it, the entire city of Munich was divided into mini 1 km x 1km squares on QGIS. It generated a much more detailed visualization of the accident percentage in Munich (Figure 7).

However, the rate of accidents does not necessarily represent how dangerous or accident-prone a location is, since the pedestrian activity is not uniform in all parts of the city. Munich experiences more pedestrian activity around the central train station, the touristy locations around Marienplatz and the central business district in general. Hence, the rate of recorded accidents is also higher around those areas. To determine the actual risk-levels, it is necessary to normalize the recorded accidents rates using the pedestrian-activity data obtained from the Mito/MoPed data.

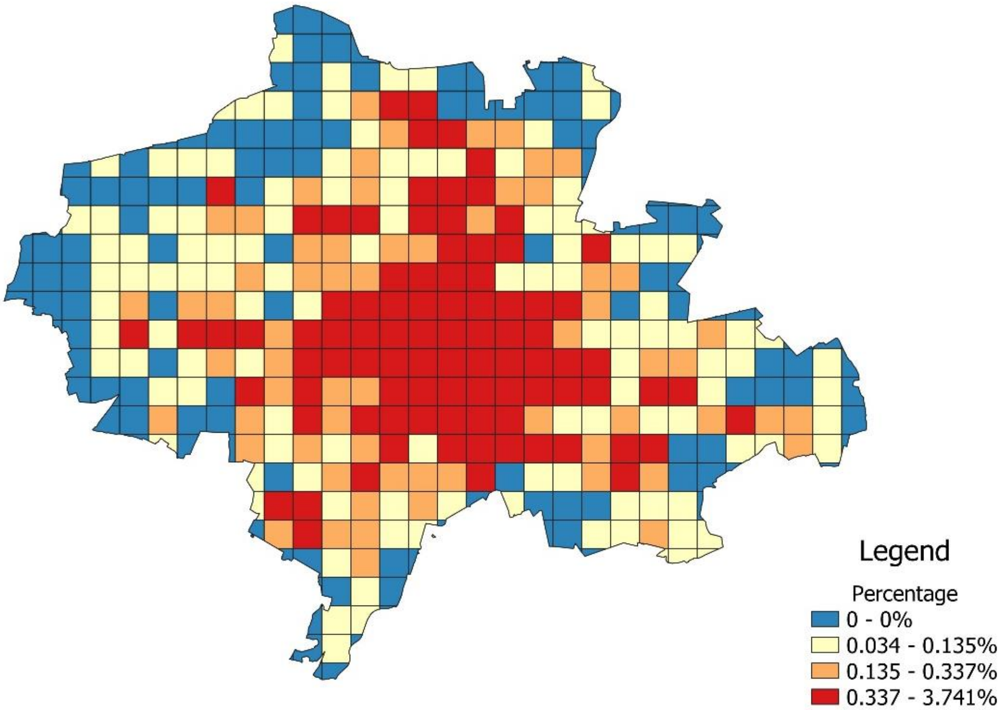

Figure 7 Percentage of total number pedestrian related accidents in 1x1 km grids

To determine pedestrian-activity rate, the origination points of the walking trips were taken into consideration, and the percentages of the number of origination points were calculated for each of the 1km x 1km squares.

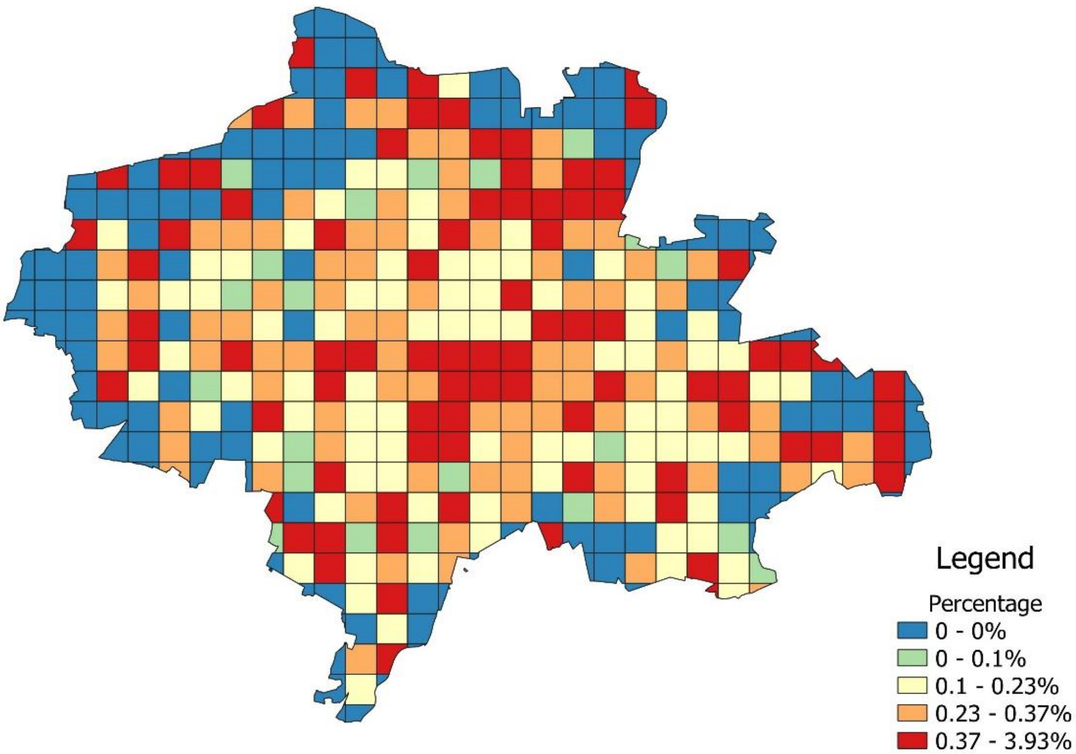

Figure 8 Normalized percentage of total number pedestrian related accidents in 1x1 km grids

To normalize the accident percentage, the following formula was used

$$Normalized\ Accident\ Value = \frac{100}{Po} * Pa$$

Where P_o = Percentage of walk-trip origins in the square

P_a = Percentage of recorded pedestrian accidents in the square

After normalization, more high-risk areas were identifiable all over Munich (Figure 8). Based on the normalized grid map, seven locations were selected for further investigation and survey (Figure 9). These locations include high-traffic intersections, accident-prone road segments, as well as one low-risk area. The selected locations are:

1. Moosacherstraße-Lerchenauerstraße intersection
2. Moosacherstraße-Schleißheimerstraße intersection
3. Frankfurter Ring-Knorrstraße intersection
4. An accident-prone segment of Leopoldstraße
5. Bayerstraße-Goethestraße intersection, near Munich Hauptbahnhof (Hbf)
6. An accident-prone segment of Lindwurmstraße
7. A relatively safer segment of Lindwurmstraße

Three consecutive intersections along a major ring road (Moosacherstraße-Frankfurter Ring) in Munich were selected for the research; the intersections with Lerchenauerstraße. Schleißheimerstraße and Knorrstraße from west to east respectively. These intersections were chosen because of their differing accident rates. The number of recorded pedestrians related accidents shows an increasing trend from west to east.

After analyzing Google Earth data and imageries, the difference in the neighborhood types and the levels of pedestrian activity in the adjacent areas seemed to be the reasons behind this gradient in accident rates. The intersection at Lerchenauerstraße is located farther from residential areas which results minimal pedestrian traffic. So, the interactions between pedestrians and vehicles are also very low. On the other hand, the Frankfurter Ring-Knorrstraße intersection is located at a much closer proximity to residential areas. It is noteworthy that the north exit of the Frankfurter Ring U-Bahn station is also located at this intersection. These factors result in much higher pedestrian activity which increase the probability of conflicts between pedestrians and vehicles.

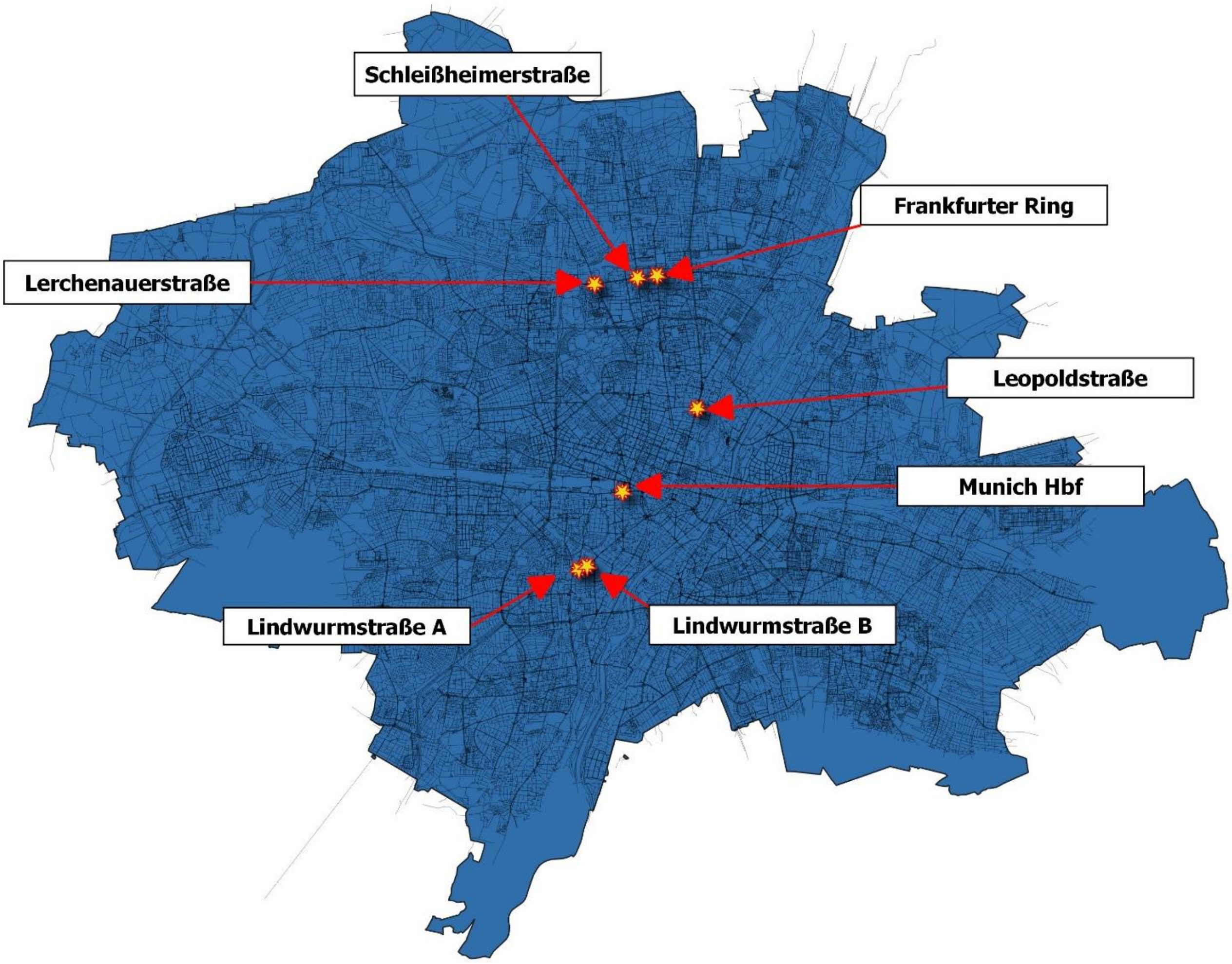

Figure 9 Locations selected for the study

The fourth location is a 300 meters segment on Leopoldstraße, where several pedestrians related accidents have been recorded from the year 2018 to 2022. The road junction between Bayerstraße and Goethestraße in front of Munich central station has been chosen as the fifth location where a big number of crashes have been recorded.

The last two locations lie on Lindwurmstraße based on the significant contrast of accident rate. Although considered safe for pedestrians across most of its length, Lindwurmstraße had several accidents recorded from the year 2018 to 2022. Especially, a 100-meter segment between Kiddlerstraße and Daiserstraße has a concerning case of pedestrian-related accidents, whereas the other much longer segment of Lindwurmstraße selected for the research was found to significantly safer for the residents who enjoy taking strolls.

Before formulating the survey questionnaires, inspections were conducted at the selected sites to gather insights into the existing anomalies with the walking infrastructures and to observe any potential abnormal behaviors of pedestrians that could contribute to crashes.

5 Site Descriptions

The inspections at the selected locations were carried out between 17:00 to 20:30 during late August to mid-September. On most days there was sufficient daylight. Since the inspections were conducted on weekdays, pedestrian movement was noticeably high during those hours. The satellite images used in this section have been retrieved from Google Earth (2024).

5.1 The Intersection Between Moosacherstraße and Lerchenauerstraße

Three pedestrian related accidents have been recorded at this intersection in the year 2018, 2019, and 2020 (Figure 10). All three crashes took place during dark hours between 17:00 and 20:00 in the months of November, February and January respectively. All the crashes involved passenger cars, and none of them caused any severe injury or casualty.

Figure 10 Intersection between Moosacherstraße and Lerchenauerstraße

Factors	Moosacherstraße	Lerchenauerstraße
Sidewalk width and type	2 meters (Separate)	2.5 meters (Separate)
Sidewalk condition	Well maintained	Well maintained
Carriageway width	25 meters (Aprx)	17 meters (Aprx)
Crossing width	5 meters	5 meters
Pedestrian green time	20 seconds	20 seconds
Greeneries	Sufficient	Sufficient
Street-side shops and activities	No	No
On-street parking	No	No

Table 3 The intersection between Moosacherstraße and Lerchenauerstraße

Observations

a. Sidewalk width is sufficient to accommodate the pedestrian flow even during busy hours.
b. Crosswalks are sufficiently wide to ensure safe crossing.
c. Roadside greenery provide a feeling of separation of the carriageway from the bicycle-way and sidewalks, which enhances the feeling of safety (Ren et al., 2023).
d. 20 seconds green time is generally sufficient for crossing Lerchenauerstraße.
e. Slow walkers, especially the older pedestrians, struggle to cross Moosacherstraße within the 20-second green light duration (Figure 11 a).

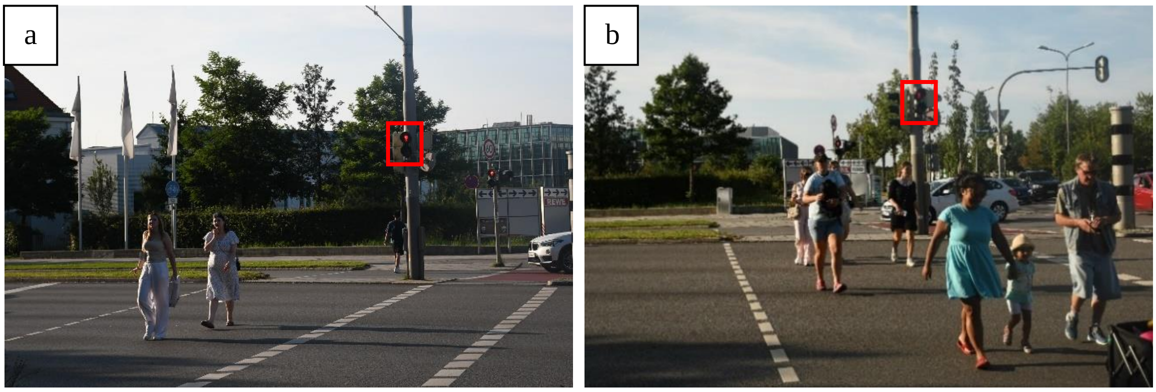

Figure 11 Pedestrians' behavior at the crosswalk (Moosacherstraße)

f. It was observed that whenever a big group of pedestrians start walking across Moosacherstraße, the signal often turns red before all pedestrians can complete the crossing, leaving 4 or 5 individuals stranded in the middle of the carriageway (Figure 11 b).
g. The crossings on Lerchenauerstraße pose risk of conflict due to the fast-paced vehicles turning right from Moosacherstraße into Lerchenauerstraße.

5.2 The Intersection Between Moosacherstraße and Schleißheimerstraße

Five pedestrians related accidents have been reported at this intersection (Figure 12). All of them took place during different months and seasons. The accidents occurred under different light conditions. Four accidents involved passenger cars and the other involved a heavy vehicle. All of them caused minor injuries.

Factors	Moosacherstraße	Schleißheimerstraße
Sidewalk width and type	2-3 meters (Separate)	2-3 meters (Separate)
Sidewalk condition	Well-maintained	Well-maintained
Carriageway width	20 meters	28 meters (North of the intersection) 16-25 meters (South of the intersection)
Crossing width	5 meters	6 meters
Pedestrian green time	20 seconds	20-40 seconds
Greeneries	Sufficient	Sufficient
Street-side shops and activities	Minimal	Minimal
On-street parking	No	Yes (North only)

Table 4 The intersection between Moosacherstraße and Schleißheimerstraße

Figure 12 The intersection between Moosacherstraße and Schleißheimerstraße

Observations

a. The sidewalk width is sufficient to accommodate pedestrian flow, during most hours.

b. There are four signalized crossings in this area. The green light duration of 20 seconds is generally adequate for pedestrians to walk across Moosacherstraße, but not always sufficient crossing Schleißheimerstraße, especially on the north side of the intersection, where the green time varies between 20 to 40 seconds.

c. Due to insufficient crossing time, pedestrians were observed on the carriageway even after the light turned red (Figure 13).

Figure 13 Pedestrians' behavior at the crossing (Moosacherstraße and Schleißheimerstraße)

d. Roadside greeneries provide a feeling of separation of the carriageway from the bicycle-way and sidewalks, which enhances the feeling of safety (Ren et al., 2023).

e. The investigation was carried out during the afternoon peak hour. A significant traffic congestion was observed on Frankfurter Ring-Moosacherstraße.

f. Several dangerous maneuvers and interactions were observed between the motor vehicles and the pedestrians.

g. Due to the presence of residential areas nearby, pedestrians' density was found to be moderately high.

5.3 Frankfurter Ring (The Intersection Between Frankfurter Ring and Knorrstraße)

Nine pedestrians related accidents have been recorded on this road segment during the year 2018-2020, and none during 2021-22 (Figure 14). Except for two, rest took place during the colder months. The crashes took place at different times of the day. Six crashes involved passenger cars, one involved a heavy vehicle and two involved bicycles. Three accidents caused severe injury, and the rest caused no major injury.

Factors	Frankfurter Ring	Knorrstraße
Sidewalk width and type	3 meters (Separate)	3 meters (Separate)
Sidewalk condition	Well maintained	Well maintained
Carriageway width	18.5 meters (Aprx)	14 meters (Aprx)
Crossing width	5 meters	5 meters
Pedestrian green time	20 seconds	20-40 seconds
Greeneries	Sufficient	Sufficient
Street-side shops and activities	Minimal	Minimal
On-street parking	Yes	Yes

Table 5 Frankfurter Ring

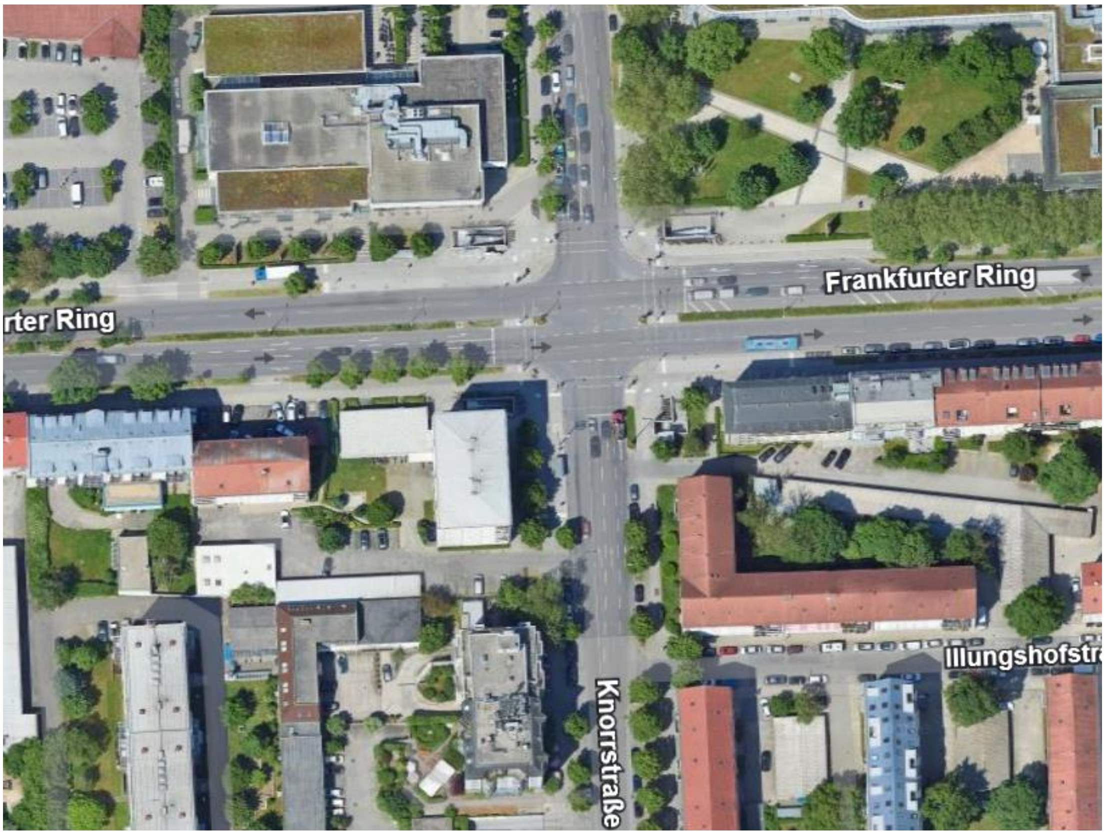

Figure 14 Frankfurter Ring (The intersection between Frankfurter Ring and Knorrstraße

Observations

a. Sidewalk width is sufficient for the pedestrian flow,

b. There are four signalized crossings in this area. The green time is sufficient for walking across Knorrstraße (20-40 seconds) but not always sufficient for crossing Frankfurter Ring.

c. Roadside greeneries provide a feeling of separation of the carriageway from the bicycle-way and sidewalks, which enhances the feeling of safety (Ren et al., 2023).

d. As the investigation was carried out during the afternoon peak hour, huge traffic congestion was observed on Frankfurter Ring. It was noticed that vehicles were not always able to drive past the intersection and the crosswalk on the opposite side within the green time (Figure 15 a). Hence, pedestrians often had to use the crosswalks across Frankfurter Ring while there were still cars on it.

e. Several dangerous maneuvers and interactions were observed between the vehicles and the pedestrians.

f. Due to the presence of Frankfurter Ring U-Bahn station and residential areas nearby, pedestrians' density was found to be exceptionally high (Figure 15 b).

g. Scattered jaywalking cases were observed on Knorrstraße, especially around Korbinianplatz bus-stop (Figure 15 c).

Figure 15 Pedestrians' behavior at the crossing (Frankfurter Ring and Knorrstraße)

5.4 Leopoldstraße (The Segment Between Ainmillerstraße and Giselastraße)

Eight pedestrian-related accidents have been recorded at this 300-meter segment between the year 2018-2022 (Figure 16). Except for one, rest took place during the warmer months. Six crashes occurred in dark conditions and two during noon time. Three crashes involved passenger cars, four involved bicycles and the last one involved both bicycles and passenger cars. One accident caused severe injury, and the rest caused no major injury.

Factors	Leopoldstraße
Sidewalk width and type	8 meters (Separate)
Sidewalk condition	Well maintained
Carriageway width	14 meters (Aprx)
Crossing width	6 meters
Pedestrian green time	20 seconds
Greeneries	Sufficient
Street-side shops and activities	Yes
On-street parking	Yes

Table 6 Leopoldstraße

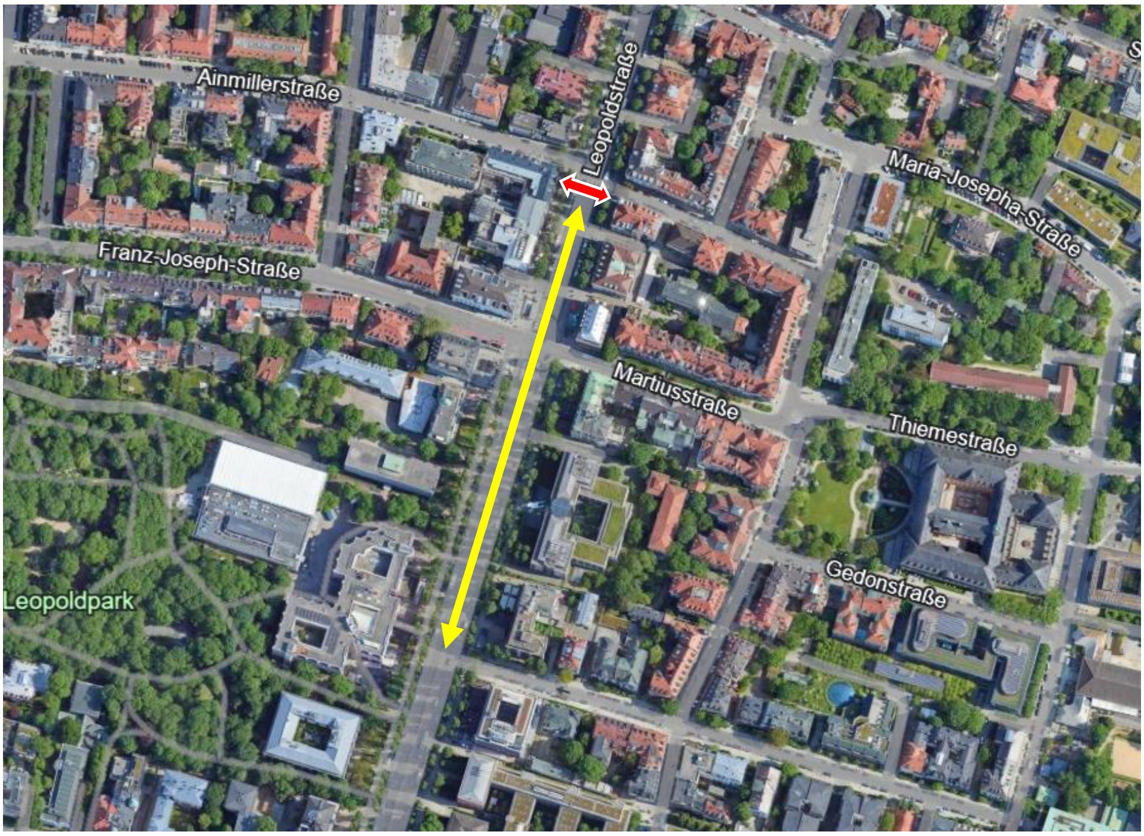

Figure 16 Leopoldstraße (The segment between Giselastraße and Ainmillerstraße)

Observations

a. Sidewalk width is sufficient for the pedestrian flow,

b. Roadside restaurants, cafes, etc. make the environment lively and attractive for walking, but the outside sittings of the cafes and restaurants make the pedestrians' movement congested and sometimes uncomfortable.

c. There is one signalized crossing within this segment of the road. The green time is sufficient for walking across Leopoldstraße.

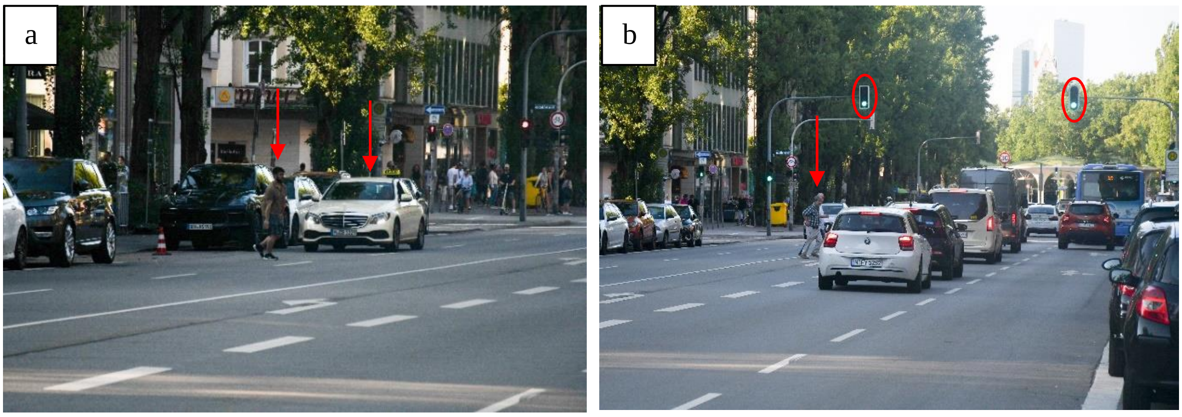

Figure 17 Pedestrian behavior at Leopoldstraße

d. Roadside greenery provides a feeling of separation of the carriageway from the bicycle-way and sidewalks, which enhances the pedestrians’ feeling of safety.
e. Due to the presence of restaurants, cafes and shops, a common tendency of jaywalking was observed among the pedestrians (Basu et al., 2022), especially around the location where Ainmillerstraße and Trautenwolfstraße meet Leopoldstraße (marked with red arrow on Figure 16)
f. Vehicles parked on the roadside cause visual obstruction; the drivers often cannot see the jaywalkers waiting between the parked vehicles until they start crossing.
g. During the 20-minute investigation, more than 30 jaywalking cases were observed (Figure 17).

5.5 The Junction Between Bayerstraße and Goethestraße near München Hbf

Nine pedestrian related accidents have been reported at this location; four in the year 2018 and four in 2020, and one in 2019 (Figure 18). The accidents took place in different seasons of the year and in different light conditions. Eight of them involved passenger vehicles and one involved a heavy vehicle. Two accidents caused severe injuries, and the rest caused no major injury.

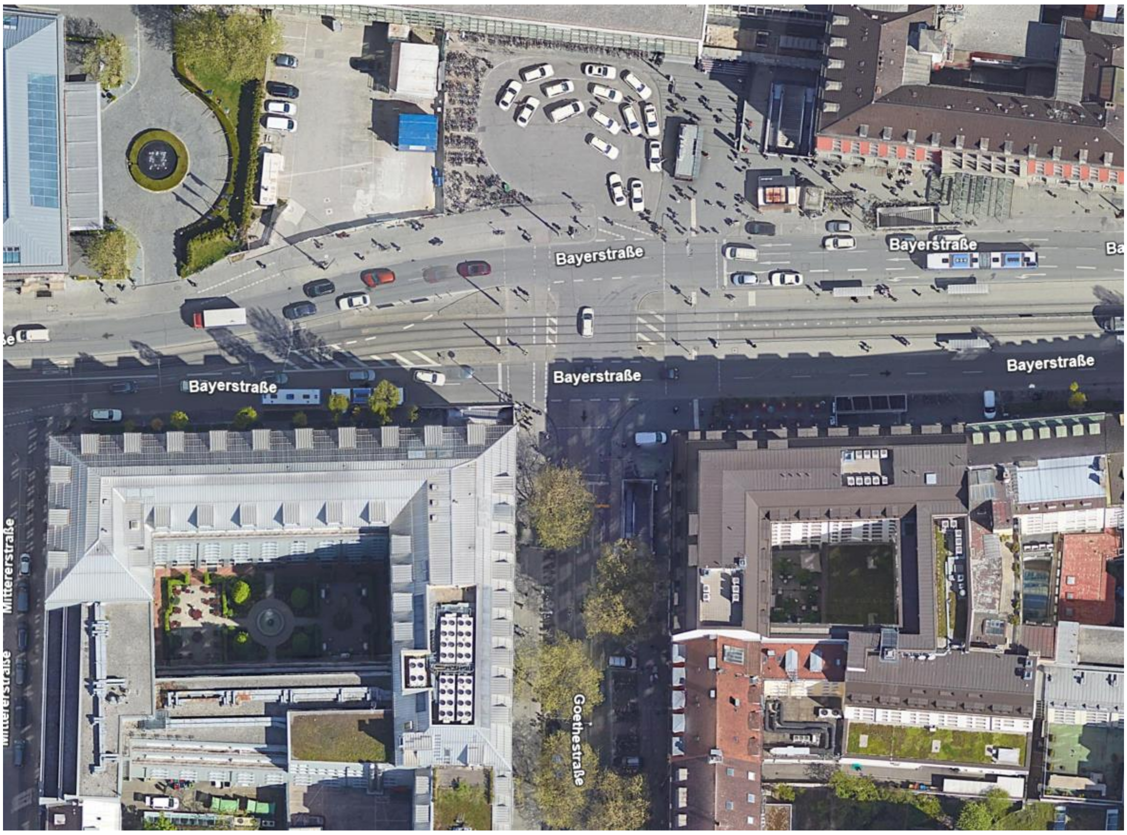

Figure 18 The junction between Bayerstraße and Goethestraße

Factors	Bayerstraße
Sidewalk width and type	6 meters (Separate)
Sidewalk condition	Reasonably maintained
Carriageway width	25 meters
Crossing width	4 meters
Pedestrian green time	22 Seconds
Greeneries	Minimal
Street-side shops and activities	Minimal
On-street parking	No

Table 7 The junction between Bayerstraße and Goethestraße

Observations

a. The location was found to be heavily crowded due to local shops and businesses, also the proximity of Munich Hbf.

b. Sidewalks were found to be congested. Hence, pedestrians cannot move comfortably.

c. Due to construction work, the sidewalks were found to be discontinuous. Navigability of the area reduced significantly due to sidewalks' closure (Casanovas-Rubio et al., 2020).

Figure 19 Pedestrian behavior at Bayerstraße

d. A general restlessness was noticed among the pedestrians, which reflects their dissatisfaction with the walking experience.
e. The allotted pedestrians green time for crossing Bayerstraße is 22 seconds, which is not enough.
f. Despite the availability of refuge island, pedestrians were observed on the carriageway even long after the light turned red (Figure 19)
g. The construction zone's barrier in the middle of Bayerstraße causes visual obstruction for drivers and pedestrians which increases the risk of collision (Gargoum & Karsten, 2021).

5.6 Lindwurmstraße A (The Segment Between Kidlerstraße and Daiserstraße)

Figure 20 The high-risk segment of Lindwurmstraße

Factors	Lindwurmstraße A
Sidewalk width and type	3-5.5 meters
Sidewalk condition	Well maintained
Carriageway width	9 meters
Crossing width	5 meters
Pedestrian green time	-
Greeneries	Sufficient
Street-side shops and activities	Minimal
On-street parking	Yes

Table 8 Lindwurmstraße A

Seven pedestrian related accidents have been recorded within this 100-meter segment from the year 2018 to 2022 (Figure 20). Six accidents took place between September to November and one in April. The accidents occurred during different light conditions. Five of them involved bicycles and the other two involved passenger cars. Five accidents caused severe injuries, and the rest two caused no major injury.

Observations

a. The area was found to be pleasant for walking. Pedestrians' presence was minimal.

b. Roadside greeneries make the area vibrant and provide a feeling of safety and calmness (Ren et al., 2023).

c. The bicycle path is laid along the carriageway for the bikers traveling eastwards, but it is along the sidewalk for the bikes traveling westwards (Figure 21 a and b).

Figure 21 Road geometry and the sidewalks at Lindwurmstraße A

d. The sidewalk width was found to be sufficiently wide for the pedestrians' volume in most parts of the area. However, it suddenly narrows from 2.5 meters to 1.2 meters at a specific location due to the curvature of the road and presence of a building. This sudden change of width and the visual obstruction caused by the building can cause collisions between pedestrians and the bikers (Figure 21 b, c and d). Since the pedestrians had most of the collisions with bicycles in this area, this fluctuation can be considered as one of the potential reasons. Additionally, the bus-stop being located beside the narrow segment of the sidewalk makes pedestrians walk across the bike-path, further increasing the chance of collisions.

e. Vehicles parked on the roadside cause visual obstruction; the drivers and bikers often cannot see the pedestrians waiting to cross the road (Mutabazi, 2010)

5.7 Lindwurmstraße B (The Segment Between Daiserstraße and Implerstraße)

Factors	Lindwurmstraße B
Sidewalk width and type	2-3.5 meters
Sidewalk condition	Well maintained
Carriageway width	12 meters
Crossing width	5 meters
Pedestrian green time	15-25 Seconds
Greeneries	Sufficient
Street-side shops and activities	Minimal
On-street parking	Yes

Table 9 Lindwurmstraße B

Three pedestrian related accidents have been recorded at this stretch of Lindwurmstraße from the year 2018 to 2022 (Figure 22). The accidents took place during different seasons. All the accidents occurred during daylight conditions. Two of them involved bicycles and the other involved a passenger car. Two accidents caused severe injuries and the other caused minor injuries.

Figure 22 The relatively safer segment of Lindwurmstraße

Observations

1. Like the previously discussed segment, this part of Lindwurmstraße was also found to be pleasant for walking. Pedestrian density was minimal (Figure 23 a and c).
2. Roadside greeneries make the area vibrant and provide a feeling of safety and calmness (Ren et al., 2023). Unlike the previous segment, bicycle path is laid along the sidewalk on both sides of the road after Aberlastraße (marked with red arrows in the Figure 22).
3. The sidewalk width was found to be sufficiently wide for the pedestrians' volume in most parts of the area. However, due to ongoing construction work, some barriers have been placed to restrict and divert movement which is affecting pedestrian comfort. Especially, the pedestrians have to share a narrow tunnel with bicycle users which increases the chances of collisions (Figure 23 b).
4. Similar construction barriers are placed at the junction where Lindwurmstraße meets Implerstraße, which deteriorate pedestrian comfort by restricting and diverting their movements (Figure 23 d).

Figure 23 Road geometry and the sidewalks at Lindwurmstraße B

5.8 Summary of Recorded Collisions

Location	Number of Accidents	Collision Type			Severity	
		With Bike	With Car	With Heavy Vehicle	Severe Injury	Minor Injury
Lerchenauerstraße x Moosacherstraße	3	0	3	0	0	3
Schleißheimerstraße x Moosacherstraße	5	0	4	1	0	5
Frankfurter Ring	9	2	6	1	3	6
Leopoldstraße	8	4	4	0	1	7
Munich Hauptbahnhof	9		8	1	2	7
Lindwurmstraße A	7	5	2	0	5	2
Lindwurmstraße B	3	2	1	0	2	1

Table 10 Recorded accidents at the selected locations

6 Analysis of Survey Data and Results

6.1 Interception Survey

A total of 191 participants took part in the survey (Table 11). Pedestrians were asked if they would be interested in contributing to improving the walking environment in their respective areas. The interested individuals were asked to fill out the survey. In addition, enthusiastic participants provided feedback on the existing problems in the area and how to make it more friendly for pedestrians.

Area	Number of Participants
Lerchenauerstraße	27
Schleißheimerstraße	25
Frankfurter Ring	25
Leopoldstraße	26
Munich Hauptbahnhof (Hbf)	38
Lindwurmstraße A	24
Lindwurmstraße B	26
Total	191

Table 11 Number of participants from each location

The survey included participants from all genders and age groups, ensuring a diverse representation of perspectives. There were reasonable numbers of respondents across all age groups, except for the 65+ age group. Only 3 participants from this age group took part in the survey. Nonetheless, the survey provides valuable insights into the perceptions of pedestrians across different gender and age groups (Figure 24).

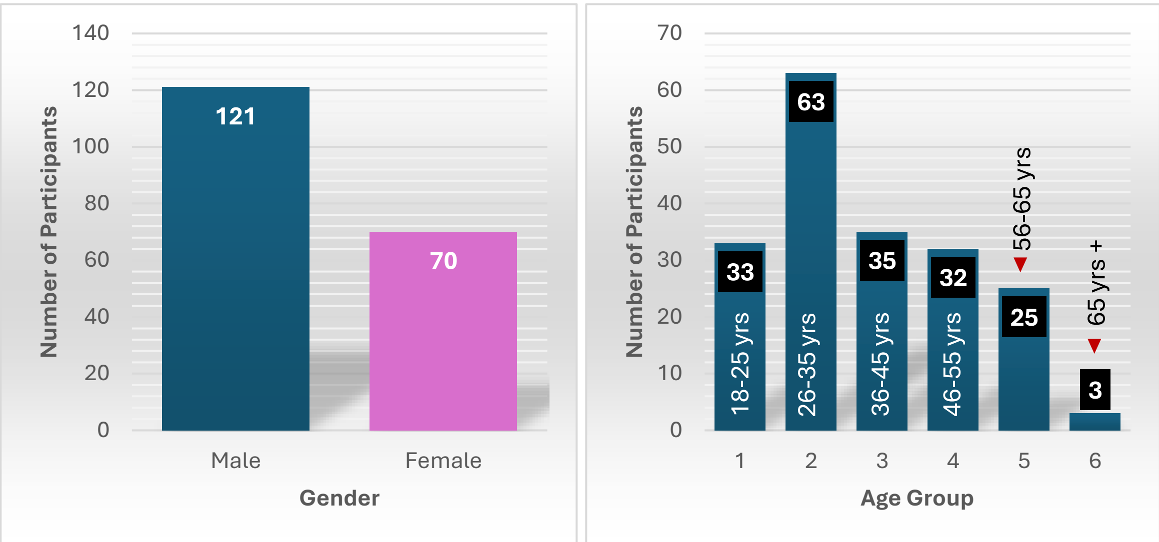

Figure 24 Gender and age-wise breakdown of the participants

Participants were also asked how much they walk on a regular day of the week. Figure 25 illustrates the breakdown of respondents into various daily walk duration groups, providing insights into walking behavior patterns across the sample population.

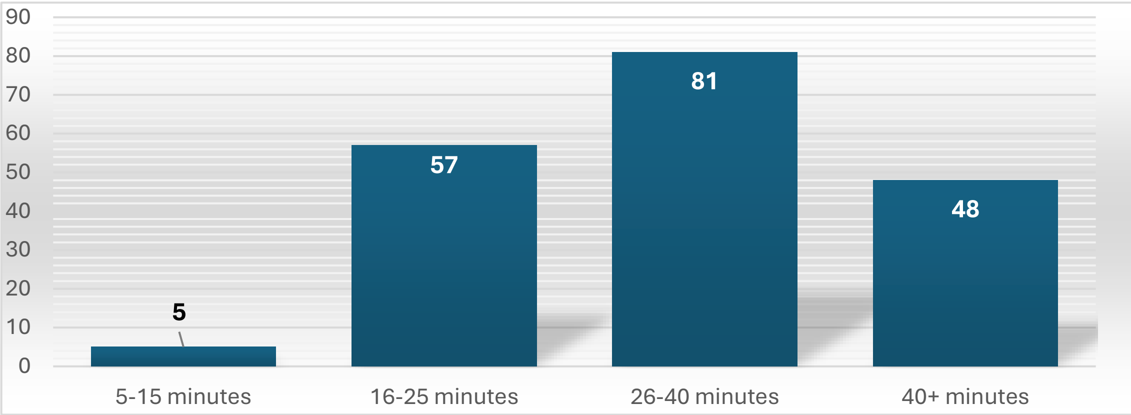

Figure 25 Summary of the daily walk-time of the participants

Feedback was collected separately for each location, demonstrating varying levels of satisfaction and dissatisfaction with the environment across different factors. Figure 26 shows the descriptive statistics of the compiled survey data from all seven locations.

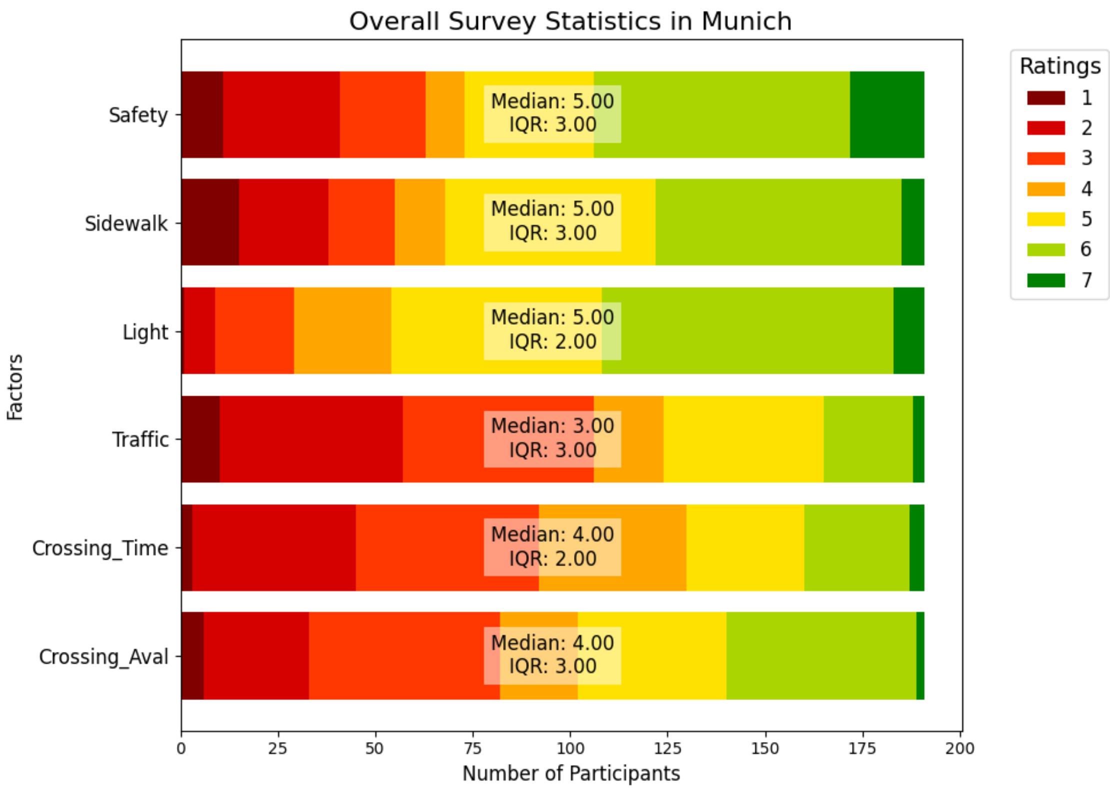

Figure 26 Compiled feedback from all over Munich

It represents the varying satisfaction level of pedestrians about overall safety and potentially influencing factors across a relatively representative variety of Munich pedestrian areas. Median and inter-quartile range of responses regarding each factor are included in the figure. For purposes of perceived satisfaction, we consider a median rating of 3 to be baseline dissatisfactory, a median rating of 4 to be neutral, and a median rating of 5 to be satisfactory. Survey statistics for the individual locations are attached as Appendix C to this report. Figure 27 shows a significant variation in overall safety ratings across the seven locations.

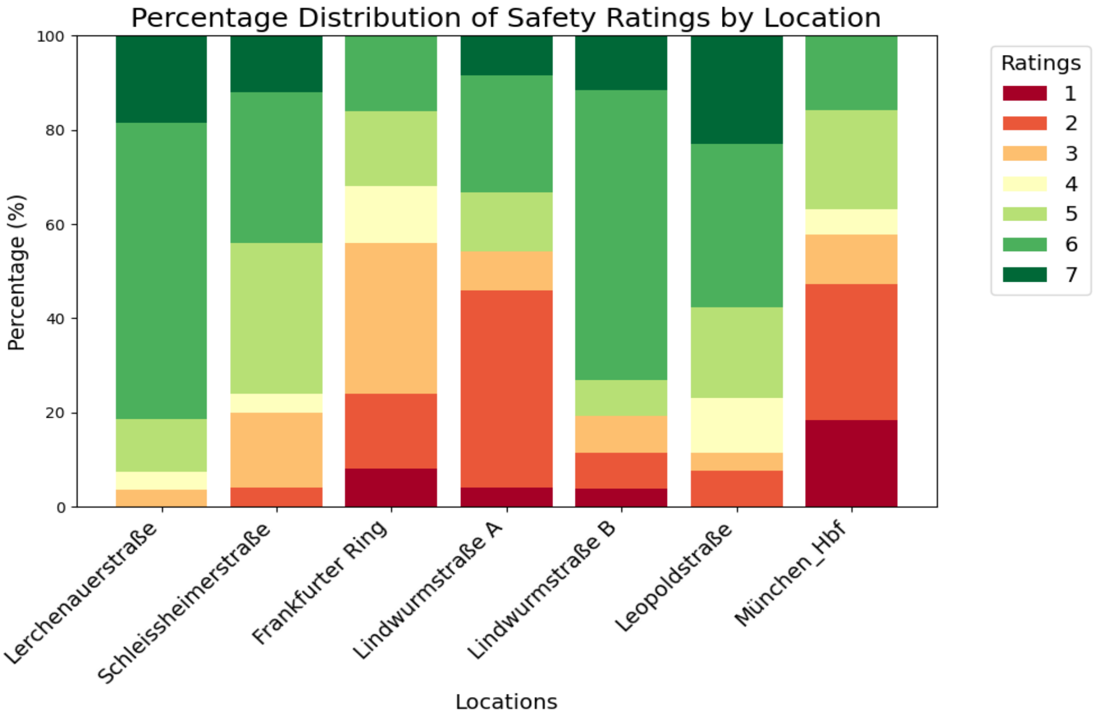

Figure 27 Variation in safety perception across the locations

Based on participants' feedback, Lerchenauerstraße and Lindwurmstraße B were perceived as the safest among the seven surveyed locations. However, despite their overall safety perception scores, many participants voiced their dissatisfaction with traffic conditions and crosswalk arrangements at these locations. Following closely were Schleißheimerstraße and Leopoldstraße. While a significant portion of respondents gave high safety scores for these areas, a notable number provided lower scores. At Schleißheimerstraße, the primary concerns were related to traffic conditions and crossing times. At Leopoldstraße, however, participants expressed dissatisfaction with sidewalk conditions, crosswalk availability, and lighting.

Munich Hbf, Frankfurter Ring, and Lindwurmstraße A ranked lowest in perceived safety among the seven locations. At Frankfurter Ring, participants highlighted their disappointment with traffic conditions and crosswalk arrangements. Meanwhile, for Lindwurmstraße A and Hauptbahnhof, dissatisfaction was widespread, with concerns raised about nearly all evaluated factors. While the responses from some locations support the findings of the field investigation, some do not.

As mentioned before, the selected locations are different in nature because of the differences in the types of neighborhoods, differences in street designs and urban layouts, varying levels of pedestrian density, etc., which is reflected by the numbers and nature of the recorded accidents (Table 10). As illustrated in Appendix C, participants' safety perceptions also differed across these locations, as did the scores assigned by them to other factors. Some locations received low scores for certain factors yet were still perceived as overall safe by most participants. To evaluate the impact of each factor on overall safety scores at each location, Spearman's correlation coefficient was calculated, the results of which are shown in Table 12. The coefficients revealed a strong correlation between safety perception and sidewalk conditions at most of the locations. Other factors also demonstrated varying levels of correlation with safety perception, which indicates the contribution of multiple elements on how pedestrians assess safety. Similar analysis on the compiled data of all locations provides a broader perspective on these correlations in Table 13.

The coefficients indicate that sidewalk conditions have the strongest correlation with pedestrians' safety perception. The availability of signalized crosswalks is the second most correlated factor, closely followed by traffic conditions. Among these five safety factors, crossing time and light condition have the lowest correlations with safety perception. The findings from this analysis also reveal that the demographic factors (gender, age, daily walk) have very insignificant relationships with perceived safety. Although insignificant, the age of the pedestrians was found to have negative correlation, which means that an older pedestrian is more likely to perceive a walking environment as unsafe than a younger pedestrian.

	Safety Perceptions at Different Locations						
Factors	**Lerchenauerstraße**	**Schleißheimerstraße**	**Frankfurter Ring**	**Lindwurmstraße A**	**Lindwurmstraße B**	**Leopoldstraße**	**München Hbf**
Gender	-0.21696	-0.0985	0.012651	-0.03199	0.178687	-0.08572	-0.0433
Age	-0.03181	-0.28452	-0.16404	-0.4636	-0.02777	-0.20032	-0.35244
Daily Walk	0.160635	-0.02153	-0.03173	-0.09235	0.012533	0.466905	0.455
Sidewalk	0.703328	0.40671	0.229855	0.792079	0.703976	0.474715	0.739926
Traffic	0.116906	0.440528	0.267547	0.641986	0.665173	0.174944	0.685745
Crossing Availability	0.311865	0.618847	0.534239	0.614263	0.620725	0.329338	0.461745
Crossing Time	0.09308	0.472254	0.317533	0.445461	0.268169	0.387754	0.269429
Light	0.398978	0.100706	-0.00863	-0.07526	0.322032	0.121767	0.517437

Highest Correlation
Second Highest Correlation

Table 12 Spearman coefficients between overall safety perception and other factors at individual locations

	Gender	**Age**	**Daily Walk**	**Safety**	**Sidewalk**	**Traffic**	**Crossing Availability**	**Crossing Time**	**Light**
Gender	1.000	-0.175	-0.004	0.015	0.022	-0.034	-0.055	0.017	0.013
Age	-0.175	1.000	-0.003	-0.177	-0.177	-0.186	-0.052	-0.208	0.038
Daily Walk	-0.004	-0.003	1.000	0.184	0.065	0.135	0.095	0.150	-0.035
Safety	0.015	-0.177	0.184	1.000	0.697	0.517	0.596	0.319	0.336
Sidewalk	0.022	-0.177	0.065	0.697	1.000	0.415	0.545	0.173	0.345
Traffic	-0.034	-0.186	0.135	0.517	0.415	1.000	0.347	0.493	0.312
Crossing Availability	-0.055	-0.052	0.095	0.596	0.545	0.347	1.000	0.183	0.406
Crossing Time	0.017	-0.208	0.150	0.319	0.173	0.493	0.183	1.000	0.099
Light	0.013	0.038	-0.035	0.336	0.345	0.312	0.406	0.099	1.000

Table 13 Spearman coefficients between overall safety perception and other factors in Munich

A statistical model can help to pinpoint the factors which have the most substantial impact on safety perception. It is possible to quantify the strength and direction of relationships between factors and perceived safety with a suitable model. It is important to mention that interactions between factors can be identified by a model, which can provide a deeper understanding than the analysis of the factors individually. Considering the ordered nature of the survey feedback, ordinal logistic regression is found suitable to acquire interpretable results on how these factors influence pedestrians' perception of safety without assuming equal distances between response categories. To carry out ordered logistic regression, dummy variables were generated. The initial dataset contains the independent variables shown in Table 14 to 17.

	Name	Description	Value
Personal Information	Gender_1	The participant is male	0-1
	Gender_2	The participant is female	0-1
	Age_1	The participant's age is between 18-25 years	0-1
	Age_2	The participant's age is between 26-35 years	0-1
	Age_3	The participant's age is between 36-45 years	0-1
	Age_4	The participant's age is between 46-55 years	0-1
	Age_5	The participant's age is between 56-65 years	0-1
	Age_6	The participant's age is above 65 years	0-1

Table 14 Personal variables

Exposure	Daily_walk_1	The participant's daily walk time on a regular day is between 5-15 minutes	0-1
	Daily_walk_2	The participant's daily walk time on a regular day is between 16-25 minutes	0-1
	Daily_walk_3	The participant's daily walk time on a regular day is between 25-40 minutes	0-1
	Daily_walk_4	The participant's daily walk time on a regular day is more than 40 minutes	0-1

Table 15 Exposure variables

Environmental Factors	Sidewalk	The participant's feedback about the quality and condition of the sidewalks at the surveyed location	1-7
	Traffic	The participant's feedback about the traffic density and speed at the surveyed location	1-7
	Crossing_Aval	The participant's feedback about the availability of signalized crosswalks at the surveyed location	1-7
	Crossing_Time	The participant's feedback about the green time allotted to the pedestrians at the crosswalks nearby	1-7
	Light	The participant's feedback about the light condition and overall visibility at the surveyed location	1-7

Table 16 Environmental variables

Location	Lerchenauerstraße	The participant's feedback is about Lerchenauerstraße-Moosacherstraße intersection	0-1
	Schleißheimerstraße	The participant's feedback is about Schleißheimerstraße - Moosacherstraße intersection	0-1
	Frankfurter Ring	The participant's feedback is about Knorrstraße -Moosacherstraße intersection	0-1
	Lindwurmstraße A	The participant's feedback is about the accident-prone segment of Lindwurmstraße	0-1
	Lindwurmstraße B	The participant's feedback is about the safer segment of Lindwurmstraße	0-1
	Leopoldstraße	The participant's feedback is about Leopoldstraße	0-1
	Munich Hbf	The participant's feedback is about the Bayerstraße-Goethestraße intersection and the adjacent areas	0-1

Table 17 Location variables

For each type of variable, the dominant groups (highest number of participants) were set as reference variables (Table 18)

Reference Variables			
Gender	Age	Daily Walk	Location
Gender_1	Age_2	Daily_walk_3	Munich Hbf

Table 18 Reference/Base variables for individual factors

Additionally, only 5 respondents were found who walk only 5-10 minutes (Daily_walk_1) every day and only 3 pedestrians over the age of 65 (Age_6) took the survey. To avoid bias and overfitting of the data they were merged with "Daily_walk_2" and "Age_5" respectively.

Name	Description	Value
Daily_walk_1	The participant's daily walk time on a regular day is between 5-25 minutes	0-1
Age_5	The participant's age is above 56 years	0-1

Table 19 Merged Variables

Since the surveys were conducted at 7 different locations, the feedback received from the participants were sometimes widely different in nature. For example, the medians of the overall Safety perception for both Lerchenauerstraße and Lindwurmstraße B were found to be 6, which means the participants perceive these 2 locations similarly safe. However, their perceptions about the other factors were not exactly same. The median for "Traffic" at Lerchenauerstraße is lower than the median for "Traffic" at Lindwurmstraße B, whereas the median for "Crossing_Aval" at the former one is much higher than the latter. Therefore, as an initial step before formal analysis, the Cronbach's alpha and Kaiser–Meyer–Olkin (KMO) values were calculated to verify the internal reliability and sample adequacy of the data. The obtained Cronbach's Alpha value was 0.72 with Confidence Interval: [0.658 0.782], and all the KMO values were above 0.68, with an overall 0.75, which means the data is reliable and sample size is adequate (Halkos et al., 2021).

The initial ordered regression was conducted taking all independent variables into consideration (except reference variables), and insignificant variables were identified based on their p-values. Although any variable with p-value more than 0.05 is theoretically considered statistically insignificant, variables with p-values up to 0.15 were considered significant during the preliminary analysis. P-values of three safety factors, namely "Sidewalk", "Traffic" and "Crossing_Aval" displayed significant influence over "Safety" perception. On the other hand, it was found that almost none of the demographic variables have any significance over "Safety" perception, except "Daily_walk_4". Among the location variables, "Lindwurmstraße A" and "Lindwurmstraße B" were found to have strong significance over perceived safety.

Before the subsequent trials, the non-significant variables were discarded, and the probable interactions among the factors were checked for significance. The analysis found six interactions between the factors which provide important insights into pedestrians' perception of safety in Munich (Table 20).

Interaction Terms	Description
DailyWalk4 & Crossing Availability interaction	The influence of improved availability of signalized crosswalks on the safety perception of pedestrians who walk more than 40 minutes on a regular day
DailyWalk4 & Leopoldstraße interaction	The influence of the walking environment at Leopoldstraße on the safety perception of pedestrians who walk more than 40 minutes on a regular day
Frankfurter Ring & Sidewalk interaction	The influence of improved sidewalk condition on pedestrians' perceived safety at Frankfurter Ring
Frankfurter Ring & Crossing Availability interaction	The influence of improved availability of signalized crosswalk on pedestrians' perceived safety at Frankfurter Ring
Leopoldstraße & Traffic interaction	The influence of improved traffic condition on pedestrians' perceived safety at Leopoldstraße
Leopoldstraße & Sidewalk interaction	The influence of improved sidewalk condition on pedestrians' perceived safety at Leopoldstraße

Table 20 Significant interactions identified among the variables

Finally, based on the deviance calculation, 20 residuals that didn't align well with the model, were discarded. Safety perception is subjective, and so are the opinions on the environmental factors considered in this study. Here, a threshold of 1.8 was used to identify the responses for which observed values significantly deviate from the predicted values, and the subsequent regressions were performed discarding them, which provided the final model shown in Table 21.

Ordered Model Results			
Dep. Variable:	Safety	Log-Likelihood:	-159.37
Model:	Ordered Model	AIC:	354.7
Method:	Maximum Likelihood	BIC:	411.3
Date:	Sun, 17 Nov 2024	Time:	14:40:59
No. Observations:	171		
Df Residuals:	153	Df Model:	12

	Coefficient	Std Err	z	P>|z|	[0.025	0.975]
Sidewalk	1.5420	0.187	8.251	0.000	1.176	1.908
Crosswalk Availability	0.9014	0.167	5.389	0.000	0.574	1.229
Traffic Condition	0.3551	0.148	2.398	0.017	0.065	0.645
Lindwurmstraße A	1.6540	0.572	2.892	0.004	0.533	2.775
Lindwurmstraße B	1.8885	0.545	3.467	0.001	0.821	2.956
Daily Walk 4 (40+ minutes)	3.9444	1.195	3.300	0.001	1.601	6.287
DailyWalk4 & Crossing Availability interaction	-0.6968	0.262	-2.656	0.008	-1.211	-0.183
DailyWalk4 & Leopoldstraße interaction	3.2362	1.191	2.718	0.007	0.902	5.570
Frankfurter Ring & Sidewalk interaction	-1.0025	0.267	-3.748	0.000	-1.527	-0.478
Frankfurter Ring & Crossing Availability interaction	0.7631	0.293	2.604	0.009	0.189	1.337
Leopoldstraße & Traffic interaction	-1.1967	0.604	-1.980	0.048	-2.381	-0.012
Leopoldstraße & Sidewalk interaction	1.3215	0.609	2.171	0.030	0.129	2.514
1/2	4.9314	0.781	6.314	0.000	3.401	6.462
2/3	1.2968	0.162	7.998	0.000	0.979	1.615
3/4	0.7107	0.203	3.498	0.000	0.312	1.109
4/5	-0.3072	0.334	-0.920	0.357	-0.961	0.347
5/6	0.8786	0.167	5.268	0.000	0.552	1.205
6/7	1.5318	0.114	13.434	0.000	1.308	1.755

Table 21 Ordered model to predict perceived safety

Results and interpretation of the findings from the model

The final statistical equation model contains only the factors and interaction terms which were found to be statistically significant in predicting how the pedestrians perceive safety in Munich.

Factors	Coefficient	Odds Ratio ($e^{Coefficient}$)	Remarks
Sidewalk	1.5420	4.676	
Crosswalk Availability	0.9014	2.463	
Traffic Conditions	0.3551	1.426	
Lindwurmstraße A	1.6540	5.23	
Lindwurmstraße B	1.8885	6.61	
Daily Walk 4 (40+ minutes)	3.9444	51.62	
DailyWalk4_Crosswalk Availability_ interaction	-0.6968	0.498	Odds ratio of improved crosswalk availability for the individuals who walk more than 40 minutes is 1.23
DailyWalk4_Leopoldstraße_ interaction	3.2362	25.45	Odds ratio at Leopoldstraße is 25.45 times higher for the individuals who walk more than 40 minutes daily
Frankfurter Ring & Sidewalk interaction	-1.0025	0.37	The sidewalk odds ratio at Frankfurter Ring is 1.715
Frankfurter Ring & Crosswalk Availability interaction	0.7631	2.15	Crosswalk availability odds ratio at Frankfurter Ring is 5.28
Leopoldstraße & Traffic interaction	-1.1967	0.30	Traffic odds ratio at Leopoldstraße is 0.43
Leopoldstraße & Sidewalk interaction	1.3215	3.75	Sidewalk odds ratio at Leopoldstraße is 17.523

Table 22 Significant factors with respective odds ratios

Among the environmental factors, sidewalk, crosswalk availability and traffic conditions were found to be the most significantly related to pedestrians' perceived safety in Munich (Table 22). The sidewalk has a positive coefficient of 1.5420 and the odds ratio was found to be 4.676, which means that for every 1-unit increase in the sidewalk rating, the odds of pedestrians having a higher safety perception are 4.676 times higher. Similarly, odds ratios found for crosswalk availability and traffic conditions are 2.463 and 1.426 respectively.

Being the primary infrastructure to facilitate pedestrian movement, it is obvious that sidewalk conditions have significant influence on the walking experience in a city. The coefficient of the interaction term between Leopoldstraße and sidewalk was found to be positive, which means that the influence of sidewalk is even higher at Leopoldstraße (odds ratio= 17.53). As mentioned before, a big portion of the sidewalks around Leopoldstraße is occupied by the open-air dining areas of the restaurants, cafes, pubs and also small grocery tents, etc. Although these installations are what makes Leopoldstraße a vibrant and happening location, they contribute to reducing walkability of the area. So, any improvement of the sidewalk condition can have more positive influence at Leopoldstraße than the other locations.

Unlike Leopoldstraße, a negative interaction can be observed between Frankfurter Ring and sidewalk condition. The interaction term has a negative coefficient making the odds ratio lower than other areas, which means the positive impact of improved sidewalk condition is comparatively lesser at Frankfurter Ring. Pedestrians experience several complexities in Frankfurter Ring, especially during peak hours. It is possible that other factors, such as traffic conditions may overshadow the benefits of improved sidewalks. Furthermore, other factors like noise or pollution may influence safety perception negatively, reducing the impacts of sidewalk improvement.

Availability of signalized crosswalk is the second most significant environmental factor identified in this study. Crosswalks provide pedestrians the opportunity to cross a street safely. Therefore, availability of signalized crosswalks can play an important role in pedestrians' safety perceptions. However, this study shows that the positive impact of better crosswalk availability is significantly less for the individuals who walk more frequently than others. The improvement in safety perception by marginal improved crosswalk availability is about 50% less for the individuals who walk more than 40 minutes every day comparing to the reference daily walk group. A possible explanation is that the individuals who walk a lot are generally more adaptable to varying walking environments. Hence, marginal changes in crosswalk availability do not influence their safety perception as much as it does to others. However, according to the ordinal model, pedestrians at Frankfurter Ring are likely to be more benefitted by any improvement in availability of crosswalks. The site inspection (page 23) revealed that pedestrians face difficulty in using crosswalks at Frankfurter Ring. Therefore, even a marginal improvement of crosswalk availability can increase the pedestrians' perceived safety greatly at Frankfurter Ring.

Although pedestrians are spared from direct interaction with vehicular traffic during much of their commutes, traffic conditions still play a significant role in shaping their safety perceptions. According to the findings of this study, improvement in traffic conditions increases the odds of pedestrians having higher perceived safety.

However, although 4 out of 8 reported accidents at Leopoldstraße involved passenger cars, the model shows that improved traffic conditions may have a negative impact on pedestrians' safety perceptions, where the odds ratio was calculated to be 0.43. To find a possible explanation of this effect, it is necessary to take a look at the findings of the site inspection (Appendix C).

Leopoldstraße was found to be one of the areas with highest pedestrian activity in this study. Due to the greenery on the sidewalks and roadside parking, the separation effect is high at this location. Therefore, it can be deducted that there can be many factors which affect pedestrians' perceived safety at this location, but traffic conditions are not one of them.

This model highlights a significant relationship between walking habits and the perception of safety among pedestrians. According to the model, the individuals who walk more than 40 minutes every day are more likely to perceive higher safety in Munich than the infrequent walkers. Higher orientation with the routes and walking environment, better physical fitness due to walking and higher adaptability are some of the probable reasons behind this phenomenon. The model also shows that the high walking group is more likely feel safe at Leopoldstraße than the individuals who don't walk as much. Due to its central location, long walkers might be regular visitors of Leopoldstraße, which enhances their comfort and trust in the available infrastructure and safety features. The frequent walking group, evidently, can adapt to the narrow and congested sidewalk condition of Leopoldstraße better than the individuals who walk less.

Among the studied areas, both locations at Lindwurmstraße showed significant influences on participants' safety perceptions. The model shows that an individual is more likely to feel safe at this Lindwurmstraße compared to the reference location, Hauptbahnhof. The area around Munich Hauptbahnhof was found to have been rated poorly across all the considered factors. Moreover, all the accidents at this location involved motor vehicles, 2 of which caused severe injuries. Therefore, it is natural that an individual is likely to feel much safer at either segment of Lindwurmstraße than at Hauptbahnhof.

Additional feedback from the participants

In addition to survey questions, participants were invited to share their views on the probable causes of accidents and suggest remedies to enhance pedestrian safety. Enthusiastic respondents provided valuable insights, repeatedly highlighting issues such as right-turning vehicles, reckless bikers, and tendency to jaywalk. These recurring concerns, along with other identified problems, emphasize the need for targeted interventions to address pedestrian safety challenges in Munich. Figure 28 shows a summary of the issues highlighted by the participants.

Figure 28 Open-ended feedback received from the participants

6.2 Online Survey

71 participants participated in the survey, where they gave feedback on their experience of walking in Munich. They were asked to rate how safe they perceive Munich for walking on a scale of 1 to 10, with 1 implying very unsafe, and 10 implying very safe. Unsurprisingly, most of the participants responded that they find Munich somewhat safe to very safe (rated 7 or higher) for walking. However, 21 participants appeared to have different opinions, who rated their safety perception 6 or less, 2 being the lowest (Figure 29).

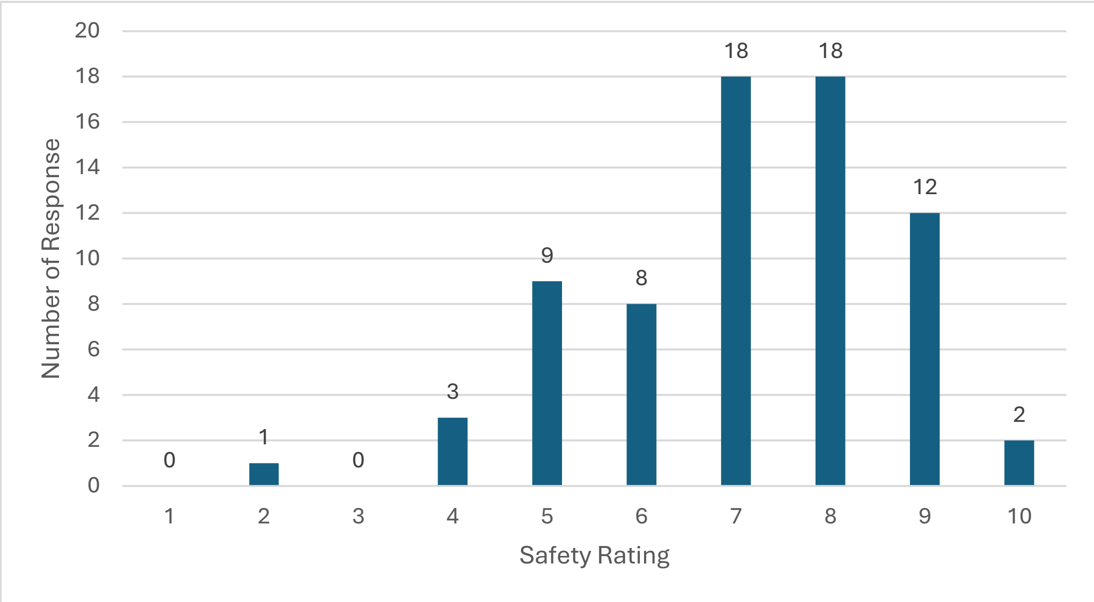

Figure 29 Participants' perception of safety in Munich

The urban environment a person grows up in, can have a remarkable influence on how they perceive safety (Côté-Lussier et al., 2015). Munich, being one of the most walkable cities in the world, should be perceived safe by someone who spent a significant portion of their life somewhere

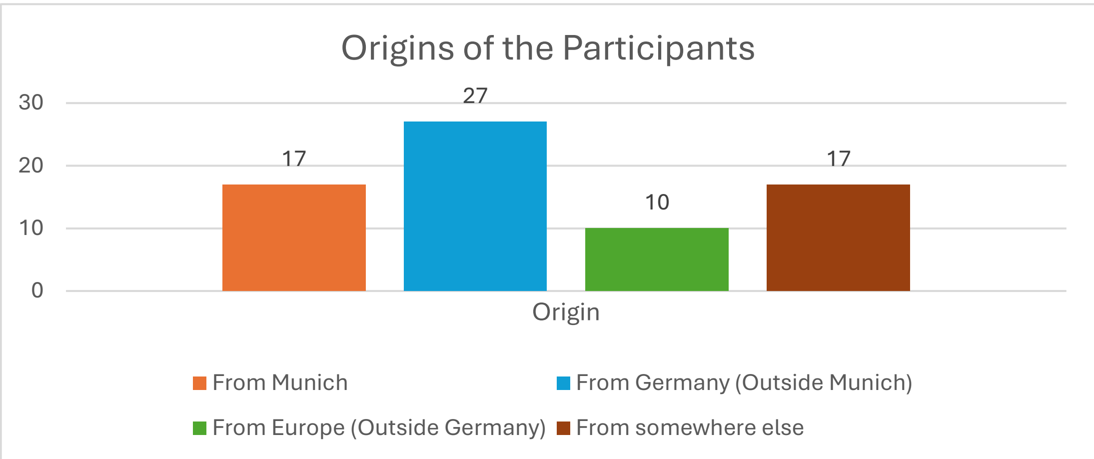

Figure 30 The number of responses from the participants of different origins

not as walkable. On the contrary, that opinion can be different from someone who spent their whole life somewhere with a better walking environment. This hypothesis led to the inclusion of a single choice question where participants were asked to select their origin from 4 options (Figure 30). Participants' responses were plotted on the graph to see how each origin group perceive safety in Munich ().

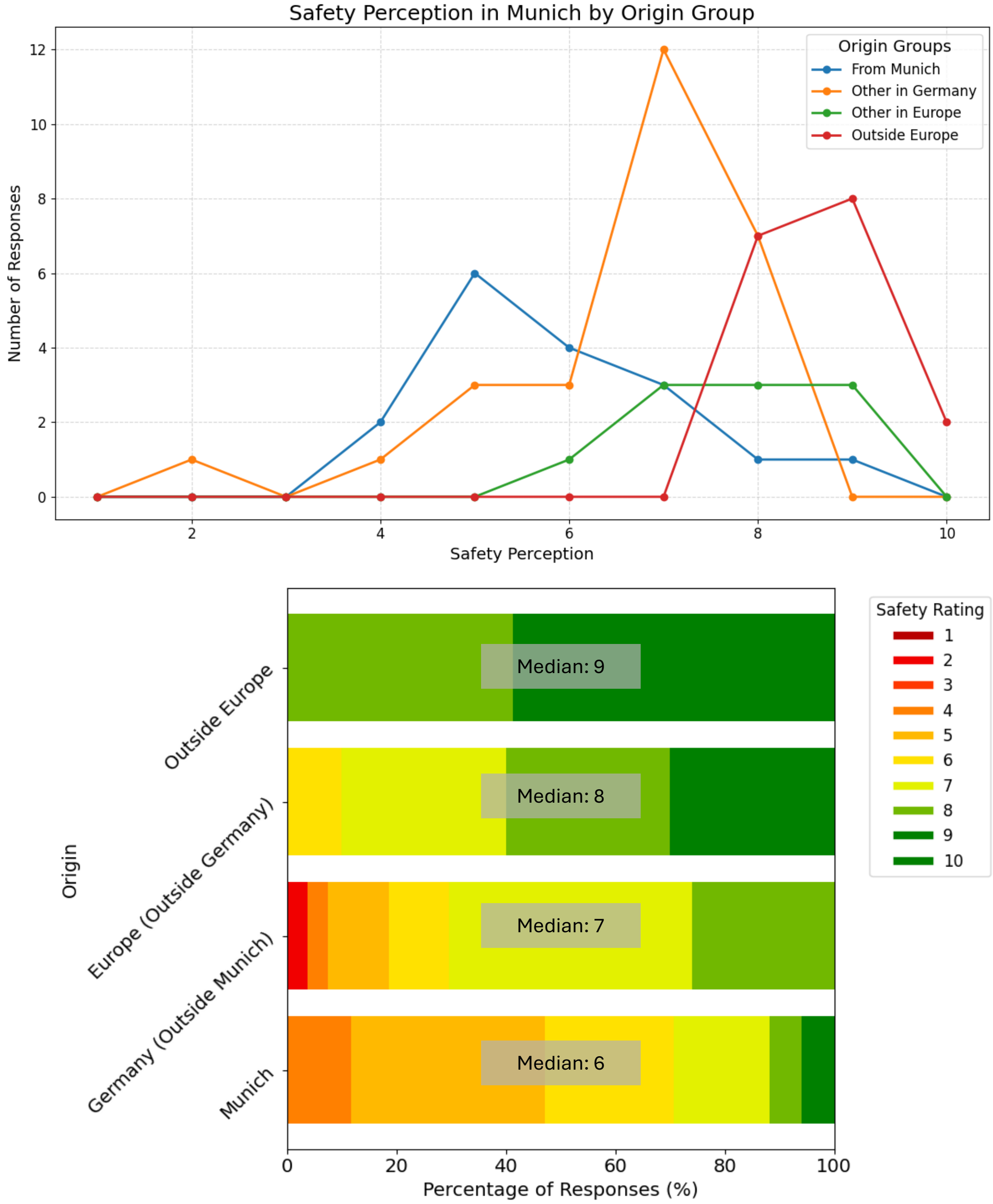

Figure 31 Variation in safety perception based on the participants' origin

A significant correlation emerged after analyzing the data on participants' origins alongside their safety ratings. While the feedback given participants from outside Germany showed median safety ratings of 8 and 9, the median of the responses from the native participants was 7. Notably, the median safety perception among Munich residents was even lower. This finding contrasts with the initial assumption that locals, being more accustomed to the urban environment, streetscapes, and areas, would perceive greater safety in Munich.

The review of past studies also revealed that pedestrians' safety perception can sometimes be influenced by their past experiences (Rod et al., 2023). For example, a location which is generally considered safe can be perceived unsafe by an individual who has experienced an accident there. To account for this, a multiple-choice question about past experiences was included in the online survey (Figure 32)

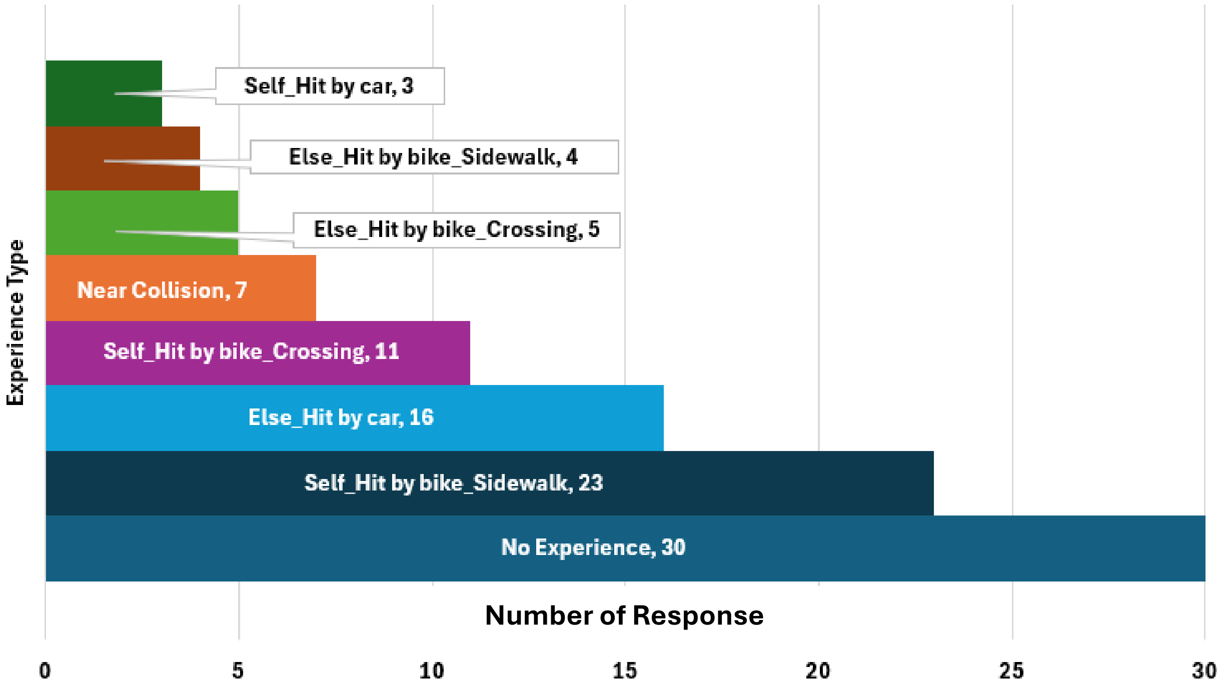

Figure 32 Participants' response regarding their past experiences

According to past studies, a trauma caused by a personal experience ought to be more impactful than a trauma caused by witnessing or knowing about someone else's experience. Secondary experiences triggers emotional responses like feelings of empathy, anger or helplessness, while personal experiences trigger more intense responses like heightened distress and impacts on personal behavior (Williamson et al., 2020). Also, different types of collisions can have different levels of impact on safety perception. For example, a person hit by a car ought to be more traumatized than a person hit by a bike (Severy et al., 1971). What makes this comparison even more complicated is that an individual can have more than one experience. The relationship between encountering successive traumatic incidents, and the resultant fear of future dangers is complex. Studies show that the Individuals experiencing several traumatic experiences were found to have higher distress and greater fear of any future trauma, which indicates that fear may accumulate rather than simply replace previous fears (Grisham et al., 2023). To analyze the impacts of different types of experiences, weights were assigned to various types of experiences to reflect their potential impact on safety perception.

Experience Type	Weight
Self- Near collision	2
Self- Hit by bike	3
Self- Hit by car	4
Secondary Experience	1

Table 23 Assigned weights for different types of experiences

These weights were used to quantify the influence of personal and secondary experiences. In cases of multiple experiences, the sum of respective values was considered as accumulated experience. Therefore, the participants with 0 accumulated experience never encountered any direct or indirect accident-related experience. On the other hand, higher accumulated values indicate a greater degree of accident-related experiences. Analysis of the participants' accumulated past experiences along with their safety ratings shows that individuals with no prior experience of accidents in Munich perceive the city to be safer than the participants with accident-related experiences (Figure 33).

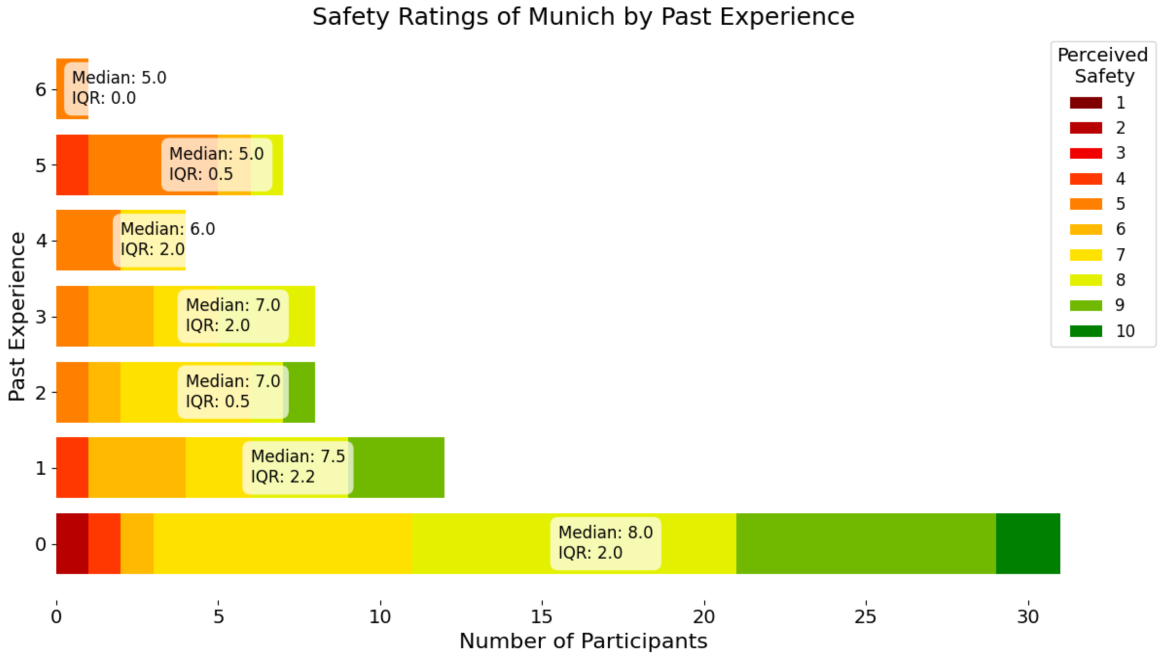

Figure 33 Variation in safety perception based on the past experiences

The final question of this survey was about the factors of walking environment which potentially influence pedestrians' safety perceptions in a city. Here, participants were asked to select the factors they considered most impactful on their sense of safety. The results highlighted sidewalk condition, separation of sidewalks from bicycle traffic, traffic conditions, and the availability of signalized crosswalks as the most critical determinants of perceived safety (Figure 34). These findings align closely with the results of the ordinal logistic model, reinforcing the importance of addressing these specific elements to enhance pedestrian safety in urban environments.

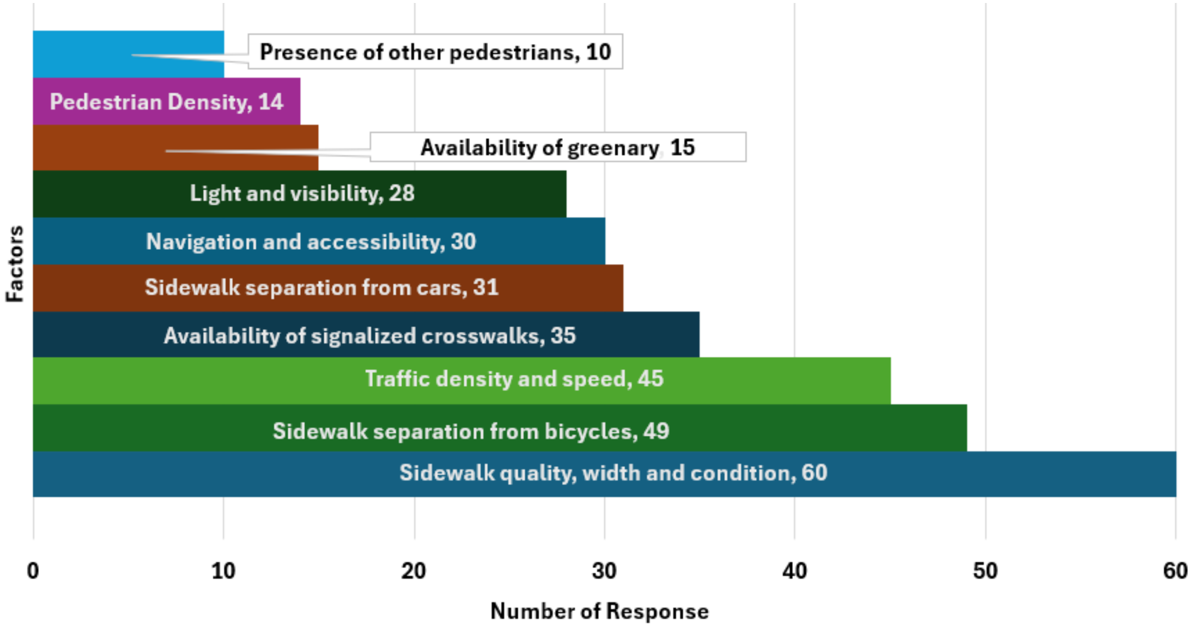

Figure 34 Environmental factors which influence pedestrians' safety perception

7 Discussion

There are myriads of factors which can influence an individual's perception of safety in an urban environment. Drawing from a review of 19 past studies, the study identified and focused on five environmental factors and five personal factors for further analysis. The findings revealed that certain environmental factors have a stronger influence on perceived safety than others. Specifically, the quality of walking infrastructure and traffic conditions emerged as key determinants. Moreover, the findings indicated that personal factors can also play a significant role in shaping pedestrians' perceptions of safety. These identified factors provide valuable insights into pedestrians' safety perception.

The statistical model reveals a strong influence of sidewalk quality and maintenance on pedestrians' safety perceptions in Munich. A comparison of field inspection findings with participants' feedback reveals that dissatisfaction with sidewalks is particularly evident at locations where they are narrow or overcrowded due to heavy foot traffic, which aligns with the findings of Sundling & Jakobsson (2023). Obstacles such as haphazardly parked bicycles, dumped construction materials, trash cans, construction barriers can make walking challenging, particularly for older pedestrians and individuals with disabilities. These obstacles were notably observed at certain locations, particularly around Munich Hauptbahnhof, where participants voiced clear dissatisfaction with the walking environment. In their study, Wu et al. (2020) highlighted the importance of obstacle free sidewalk in generating sense of safety among pedestrians. Several other studies mentioned how sufficiently wide and well-maintained sidewalks enhance pedestrians' comfort and perceived safety (Andersson et al., 2023) (Mukherjee & Mitra, 2022).

The impact of the availability of signalized crosswalks was found to be almost equally significant in enhancing pedestrians' perceived safety according to the statistical model. Past studies, however, show that the availability of crosswalks solely does not guarantee a feeling of safety. The quality of surrounding infrastructures and traffic conditions need to be pleasant along with the availability of crosswalks (Kim et al., 2024). According to Jaberolansar (2018), townscape factors such as legibility and visual pleasure, which are linked to street connectivity and integration can positively influence safety perceptions of the pedestrians in a city. Easily navigable and well-designed, especially the ladder-pattern crosswalks might contribute to positive townscape factors. Additionally, several other studies emphasize the significance of well-marked and accessible crosswalks in improving the pedestrian experience and fostering a sense of safety (Kemnitzer et al., 2019) (Cox et al., 2017) (Distefano & Leonardi, 2023). However, the allotted green time for crossing was found to be statistically insignificant. While some study areas were identified as having green times that were too short, this factor does not appear to significantly influence pedestrians' safety perceptions.

The model indicates a strong influence of traffic conditions on pedestrians' perceived safety in an urban setting. Several reviewed literatures identified strong links between the perception of traffic and the perception of safety. According to Kemnitzer et al. (2019), factors like approaching vehicle speed and vehicular traffic, along with disorderly traffic movement significantly increase the risk of pedestrian injury. Xu et al. (2018) mention the influences of traffic conditions on both pedestrian behavior and safety. When the traffic density is lower, the pedestrians feel less overwhelmed. It also allows drivers and pedestrians to see one another from a higher distance. Additionally, vehicles at low speed allow the driver to have more reaction time to brake or maneuver to avoid accidents, thus make the pedestrians feel safer (Pang et al., 2015). Beyond the risk of collisions and injuries, traffic noise also affects walking behavior and pedestrians' sense of safety (Andersson et al., 2023). Therefore, the findings of this study align well with those literatures.

The model found no significant influence of light conditions and visibility on the safety perceptions of the pedestrians in Munich. This aligns with the results from the online survey, where participants did not prioritize these factors as crucial for their safety perception while walking. Instead, the participants overwhelmingly highlighted the importance of sidewalk quality, availability of safe crosswalks, and traffic conditions. These environmental factors were consistently rated as most important when it comes to feeling safe while walking through the city. This highlights that pedestrians emphasize more the elements which are directly related to their physical interaction with the built environment and traffic, compared to the abstract factors like lighting and visibility.

Some of the past research pointed out that gender and age can play a significant role in shaping an individual's perceived safety. Kemnitzer et al. (2019) argued that women often report feeling less safe due to their heightened awareness of potential dangers in traffic situations. On the other hand, Rod et al. (2023) highlighted that older adults are inequitably affected by both objective and subjective risks, which can impact their perceived safety and deter them from walking. However, no significant relationship with gender or age was found in this study. Instead, a strong link was found between pedestrians' walking habits and sense of safety. The study shows that the individuals who walk more regularly are likely to have higher safety perceptions while navigating through a city on foot. Interestingly, it was found that the positive effects of higher availability of signalized crosswalks are less significant for frequent walkers. The model also indicates that frequent walkers tend to feel safer in areas with high pedestrian activity compared to infrequent walkers. These phenomena can be explained in several ways. Aside from their better physical fitness and higher adaptability, frequent walkers tend to have better orientation with the city's streetscape which helps them choose the better routes and avoid the unsafe ones (Campos Ferreira et al., 2022). Moreover, their comfort with walking longer distances make them more willing to take detours or walk additional distances to access crosswalks, reducing their reliance on immediate crossing opportunities. Alternatively, it is also possible that people who do not find walking safe may naturally limit their daily walking duration, leaving the ones with higher perceived safety to represent the long-walking group. This is another probable reason why safety perception was found to be higher among the people who walk more than the others. According to Rod et al. (2023), those who walk less frequently tend to have a higher perceived risk of injury, which suggests a potential cycle where reduced physical activity because of perceived risk can further increase this risk perception.

A notable finding from the model was the discrepancy between the subjective safety perception and the objective safety conditions of certain locations. One of the target areas, Lindwurmstraße A, which was primarily selected due to the exceptionally high frequency of pedestrian related accidents, appeared to be perceived significantly safer by the pedestrians compared to the reference location. This contradiction might stem from various factors, such as infrastructure quality, street designs, pedestrian density, overall ambience etc. According to the data obtained from Unfallatlas, five of the seven pedestrian-related accidents which occurred at this location involved bicycles and five of them caused severe injuries. During the field inspection, the study identified a high-risk segment of the sidewalk as a likely contributor to these frequent collisions between pedestrians and cyclists. In contrast, Munich Hauptbahnhof, the reference location, recorded nine pedestrian-related accidents involving passenger cars or heavy vehicles, with only two resulting in severe injuries. Despite the higher number of severe accidents, Lindwurmstraße A is perceived as significantly safer by pedestrians. This disparity in the model's results indicates that collisions involving bicycles have a lesser impact on pedestrians' safety perceptions compared to collisions with cars or heavier vehicles.

The studied locations were found to have challenges distinct from each other. Some locations have inadequate walking space on sidewalks, some locations have high pedestrian volume, some appear to have chaotic traffic-pedestrian interactions, and so on. The statistical model emphasized identification of the right problem when improvements are planned for a specific area. The model shows that improvements in an unrelated or less significant issue may not yield the desired positive effects, it may even further deteriorate safety perceptions. For instance, in an area like Leopoldstraße where pedestrians' low safety perception is likely caused by inadequate sidewalk width or high pedestrian density, improving crosswalk availability may not result in any meaningful enhancement to their safety perception. Instead, such misaligned efforts may divert attention from addressing the important issue, which may potentially increase the dissatisfaction among pedestrians. The statistical model indicates that improving traffic conditions at Leopoldstraße may reduce the probability of pedestrians feeling safe. Although this seems unrealistic, it may have other implications.

During the site inspection, a widespread tendency of jaywalking was observed at Leopoldstraße, which led to the assumption that unregulated jaywalking is a significant contributor to pedestrian-related accidents at this location. The feedback from the participants and the model suggest that people are aware that it is not the traffic, but rather the pedestrian-behavior at Leopoldstraße which causes accidents. This leads them to the skepticism about whether improved traffic conditions truly translate into safety. Improving traffic situation may even encourage more people to walk in this area, which will result in even higher pedestrian density. Furthermore, it can be deducted that there can be many factors which affect pedestrians' perceived safety at this location, but traffic conditions are not one of them.

Additionally, a location can have more than one factor affecting pedestrians' perceived safety, such as Frankfurter Ring where heavy pedestrian density, traffic congestion and crossing difficulties all were observed during afternoon peak hours. However, the model indicates that pedestrians' safety perception is more strongly linked to their discomfort with crossing situation at Frankfurter Ring, than the other persisting issues.

This study explored various demographic and psychological factors to understand their relationships with how pedestrians perceive a certain environment. Some feedback gathered during the interception survey revealed strong dissatisfaction with safety perceptions in Munich. Since no significant influence of age or gender was identified by the model, the study delved deeper into the origins and past experiences of participants as potential influencing factors. The findings indicate that individuals born and possibly having spent a significant portion of their lives outside Europe perceive Munich to be very safe. This perception tends to diminish for individuals of European origin, with the scores dropping even further among Germans. Interestingly, the lowest perceived safety scores came from the individuals who are originally from Munich. These findings contradict the theory proposed by F. Zhang et al. (2021) that individuals are more likely to feel safer in environments similar to those they are accustomed to. However, a different study shows that the individuals who grow up in safer cities or neighborhoods with highly maintained infrastructure and better lighting tend to have higher baseline expectations when it comes to safety (Zeng et al., 2022). Based on this, it can be inferred that the locals of Munich have much higher standards for an urban environment to feel completely safe and may evaluate the city's safety situation more critically than non-locals or those from regions with less developed urban infrastructure. This nuanced understanding of safety perception underscores the importance of taking cultural differences when interpreting feedback from the residents.

According to the findings of this study, past experiences of an individual can play a significant role in shaping their perceived safety. A study by Weinstein (1989) discussed how individuals adjust their behavior based on past experiences, especially in safety-related contexts. Later, another study revealed that negative experiences at a location can reduce perceived safety of the commuters (Rod et al., 2023). The results from the online survey revealed a correlation between the number and types of past accidents or negative experiences and a deterioration in safety perception. This relationship underscores the psychological impact of past incidents on safety perception, which infers that an individual carrying memories of negative incidents may perceive higher levels of risk at a location which is objectively safe. However, these findings contradict with the findings of Ngueutsa & Kouabenan (2017), who suggested that encountering multiple accidents can diminish an individual's perception of risk. A recent study on the psychological impact of traffic accident by Marasini et al. (2022) suggests that traffic accidents can increase the risk of PTSD, depression, and anxiety, which can contribute to a pessimistic outlook on life and a lower perceived safety if these issues remain untreated.

The analysis also indicates that the psychological impact of collisions with motor vehicles is significantly stronger on pedestrians' safety perceptions than collisions with bicycles. This phenomenon explains the higher safety perception at the high-risk segment of Lindwurmstraße despite having recorded large number of pedestrian-bicyclist collisions. In their study, Mesimäki & Luoma (2021) pointed out that many pedestrian-bicyclist collisions go unreported, while occurrences of near-accident incidents between pedestrian-bicyclist are also very common. This aligns with the general understanding that collisions involving motor vehicles are often associated with more severe injuries and greater perceived danger, which can lead to long-lasting psychological effects.

8. Conclusion

As cities worldwide increasingly prioritize urban safety and livability, the importance of understanding and addressing pedestrians' safety perceptions cannot be overstated. Perceived safety is becoming an important aspect of transport safety research, as it can provide a more detailed understanding of commuters’ mode choice and behavior. This study was aimed at contributing to the growing body of research by connecting walking environments to pedestrians’ psychology and safety perceptions. The studied factors were categorized into two primary groups – environmental factors and personal/psychological factors with a view to provide nuanced insights which can help urban planners and policymakers in transforming the cities to be more walkable.

This study highlights the complex interplay between physical and psychological aspects of safety perception. The key findings are:

- High-quality pedestrian infrastructures, such as sidewalks and availability of well-marked signalized crosswalks can significantly boost the safety perception of pedestrians.
- Traffic conditions have significant influence on how pedestrians perceive safety in a neighborhood.
- Habit of walking regularly enhances an individual’s confidence to walk, thus increasing their perception of safety.
- Psychological factors, such as memories of past accidents or individual expectations can influence an individual's expectations to feel perfectly safe in a city or neighborhood.

The findings also emphasize the necessity of precise identification of the problem while planning enhancement to the urban environments. Taking the diversity of demographic and psychological dimensions, a systematic understanding of the pedestrians’ needs is crucial. It is also important to focus on the right problems persistent at a location and align the interventions with user expectations. This approach will not only enhance walkability and public health but will also foster higher perceptions of safety.

8.1 Limitations of the Study

Although this study captured many aspects of pedestrians’ safety perception, there are limitations that need to be addressed. The population and environments analyzed in this study are in Munich, Germany, offering insights into pedestrian safety perceptions in a developed European urban setting. Therefore, necessary discretion is advised when translating the findings to other cities where population density, traffic characteristics, infrastructure quality, safety culture and demographics are different. Moreover, the accident data collected from Unfallatlas do not provide a comprehensive depiction of the accidents. For instance, some accident locations are marked in the middle of the carriageway, despite being reported as collisions between pedestrians and bicycles. Analysis of Google Earth images and site inspections revealed that the bicycle paths are adjacent to the sidewalks in those areas. Therefore, several deductions about the probable causes of these accidents were drawn based on reasonable assumptions derived from real-time observations. During the site inspection, at least four pedestrian-bicyclist collisions were observed at more than two locations. Although these incidents were not severe, they highlight critical issues with the sidewalk and bike path layouts that require attention. It is also likely that many similar collisions go unreported throughout the year, underscoring the need for a deeper investigation into infrastructure design.

The interception survey was conducted during the afternoon peak hours on different days. Although the questions were designed to obtain feedback about their general impression of the area, the feedback obtained may not represent the pedestrians' perceptions about the walking environments at other times of the day. Moreover, the responses are subject to individual perceptions and biases of the participants, which means, the accuracy of the model is dependent on their ability to accurately express their opinions. Also, this study focused on only seven specific locations in Munich. Therefore, the findings from the statistical model may not apply to the whole of Munich, or other cities with different characteristics. Although 191 participants provided valuable feedback in total, the number of participants from each location was between 24 to 40. Their feedback widely varied due to the differences between these location clusters. This may have affected the robustness of the statistical model. The participants' gender representation remained binary between male and female, no diverse or transgender individual participated in the survey. Therefore, the study was not perfectly inclusive.

The online survey attempted to find how factors like pedestrians' origins and negative experiences influence their perceived safety. Although the findings were reasonable, they were not entirely conclusive. For instance, Munich locals rated their safety perception significantly lower than participants from other regions, which the study attributed to higher baseline expectations among the locals. However, this explanation may not fully account for the observed trend, leaving room for further exploration of other potential factors influencing their perceptions.

The idea of including the questions regarding individuals' experiences (upbringing and accidents) came up after conducting the interception survey. Therefore, they were included in the online survey. Inclusion of these two questions in the interception survey would provide a much deeper understanding of how the psychological factors impact an individual's perceptions about environmental factors.

8.2 Recommendations

Based on the findings of the study, several recommendations can be made to enhance the perception of safety among pedestrians and improve the overall walking experience in Munich. These suggestions are grounded in the survey results and their implementation can play a crucial role in encouraging active mobility.

Further Research

- Future research should focus on identifying specific sidewalk properties, such as width, surface quality, and separation from traffic, that most strongly influence pedestrians' perceived safety. Additionally, detailed investigations into crosswalk properties, such as design, visibility, and signal timing, are crucial.
- Psychological aspects of safety perception also warrant deeper exploration to understand how individual experiences and expectations shape subjective views of the same environment.

Policy Recommendations

- Municipal authorities should emphasize the enhancements of sidewalk conditions and crosswalk availability, especially in the areas where traffic volume is high. Crosswalk placement, design, signal timing should be planned to align with the pedestrians' requirements. Especially, opinions of the locals or long-term residents should be prioritized, as they have more experience of commuting in their city. Additionally, it is important to invest in high-quality materials and regular maintenance of the sidewalks.
- Creation of pedestrian-only zones can contribute greatly to encouraging the city residents to regularly engage in walking, by providing them with safe and stress-free environments. Introduction of traffic calming measures or strict implementation of speed limits can substantially lower collision risks in areas with high jaywalking activity. These actions can enhance pedestrians' safety perceptions, making walking a more appealing and viable option for urban mobility.

- Establishing community groups for the individuals who experienced accidents or other negative incidents can provide them with a platform to share their experiences. Such groups can enable participants to provide feedback on preventing future accidents and improving safety, fostering a sense of inclusion and consideration by municipal authorities. A platform like this can also help them realize that they are not alone in their experiences, promoting mutual support and resilience within the community.

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Declaration of Independent Work

I hereby confirm that this thesis was written independently by myself without the use of any sources and resources beyond those cited, and all passages and ideas taken from other sources are cited accordingly. In some sections, Artificial Intelligence (AI) was used for linguistic improvement. The contents regenerated by AI were reviewed and edited as needed, and I take full responsibility for the content of this report. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, 2025.01.20

Appendices

Appendix A: Survey Questionnaire

Interception Survey Questionnaire

Question Group - 1

1. How would you describe your gender?
    - Male
    - Female
    - Diverse
    - I prefer not to answer
2. Which age group do you belong to?
    - 18-25 yrs
    - 26-35 yrs
    - 36-45 yrs
    - 46-55 yrs
    - 56-65 yrs
    - Above 65 yrs
3. How many minutes do you walk on a regular day?
    - 5-15 minutes
    - 16-25 minutes
    - 26- 40 minutes
    - More than 40 minutes

Question Group – 2

Participants were presented with these statements in separate questions and were asked to indicate their level of agreement on a seven-point Likert scale. This scale allowed them to express their agreement or disagreement ranging from "Strongly Disagree" to "Strongly Agree," providing a nuanced understanding of their perspectives on each statement.

4. *"I find this area pleasant and safe for walking"*

5. *"I think, the type and width of the sidewalks in this area are perfect for ensuring safety of the pedestrians. I do not find it risky or uncomfortable at all."*

6. *"I think the vehicles' speed and density are not threatening for my safety when I walk in this area. I never feel the risk of getting hit by a vehicle."*

7. *"I think there are enough crosswalks in this area to cross the roads safely. I don't have to walk too much to get to a signalized crosswalk."*

8. *"I think the green-light time given to the pedestrians to cross the street is perfectly enough. I don't have to rush or walk too fast to cross the street within the green-light time."*

9. *"This area has good light condition and visibility both during day and night condition. I don't face any difficulty in walking due to darkness."*

Online Survey Questionnaire

Question Group - 1

1. How would you describe your gender?
    - Male
    - Female
    - Diverse
    - I prefer not to answer
2. Which age group do you belong to?
    - 18-25 yrs
    - 26-35 yrs
    - 36-45 yrs
    - 46-55 yrs
    - 56-65 yrs
    - Above 65 yrs
3. How many minutes do you walk on a regular day?
    - 5-15 minutes
    - 16-25 minutes
    - 26- 40 minutes
    - More than 40 minutes
4. Are you originally from Munich or some other city/country?
    - Originally from Munich
    - From somewhere else in Germany
    - From somewhere else (in Europe)
    - From somewhere else (not in Europe)

Question Group – 2

5. On a scale of 1 to 10, 1 being very unsafe and 10 being very safe, how would you rate your walking experience in Munich.
    - Select a real value between 1 and 10
6. Have you ever been hit by a car or a bicycle while walking in Munich? Answer this question only if your answer is yes
    - I almost got hit by a car once, but luckily it didn't happen
    - Yes, myself, by a car
    - Yes, someone close to me
    - Yes, myself, by a bike at a crossing
    - Yes, someone close to me, by a bike at a crossing
    - Yes, myself, by a bike on the sidewalk
    - Yes, someone close to me, myself, by a bike on the sidewalk
7. There can be several factors which influence how safe we feel or how much we enjoy walking in a city or neighborhood. Choose the factors which you think are most important from the list below.
    - Width, walking space and condition of the sidewalks
    - Separation of the sidewalks from motorized traffic

- Separation of the sidewalks from bicycles
- Presence of other pedestrians in the area
- Pedestrian density
- Traffic density and speed
- Availability of signalized crosswalk
- Availability of greenery along the sidewalks
- Light condition and visibility
- Navigability (Presence of street markings and direction signs)

Appendix B: Data Types and Descriptions Available in Unfallatlas

Table 24 Unfallatlas Data

	Column Name	Description of Content
General Information, Location and Time of the Accident	ID	Serial number of accidents (one record per accident)
	ULAND	01 = Schleswig-Holstein (data from 2016) 02 = Hamburg (data from 2016) 03 = Lower Saxony (data from 2017) 04 = Bremen (data from 2016) 05 = North Rhine-Westphalia (data from 2019) 06 = Hesse (data from 2016) 07 = Rhineland-Palatinate (data from 2017) 08 = Baden-Württemberg (data from 2016) 09 = Bavaria (data from 2016) 10 = Saarland (data from 2017) 11 = Berlin (data from 2018) 12 = Brandenburg (data from 2017) 13 = Mecklenburg-Western Pomerania (data from 2020) 14 = Saxony (data from 2016) 15 = Saxony-Anhalt (data from 2017) 16 = Thuringia (data from 2019
	UREGEBZ	Government district, combined with the state's code (ULAND) for official municipality keys.
	UKREIS	District
	UGEMEINDE	Municipality
	UJAHR	Accident year
	UMONAT	Accident month
	USTUNDE	Accident hour
	UWOCHENTAG	Wochentag 1 = Sonntag 2 = Montag 3 = Dienstag 4 = Mittwoch 5 = Donnerstag 6 = Freitag 7 = Samstag
Accident Data	UKATEGORIE	Accident category (based on the most severe outcome) 1 = Accident with fatalities 2 = Accident with serious injuries 3 = Accident with minor injuries
	UART	Type of accident 1 = Collision with starting/stopping/stationary vehicle 2 = Collision with vehicle in front/waiting 3 = Collision with vehicle moving in the same direction 4 = Collision with oncoming vehicle 5 = Collision with turning/crossing vehicle 6 = Collision between vehicle and pedestrian 7 = Impact on road obstacles 8 = Departure from the road to the right 9 = Departure from the road to the left 0 = Other types of accidents

	UTYP1	Accident type 1 = Driving accident 2 = Turning accident 3 = Accident involving entering/crossing 4 = Pedestrian crossing accident 5 = Accident involving parked vehicles 6 = Longitudinal traffic accident 7 = Other types of accidents
	ULICHTVERH	Lighting conditions 0 = Daylight 1 = Twilight 2 = Darkness
	IstRad	Accident involving bicycles 0 = No bicycle involvement 1 = Bicycle involvement
	IstPKW	Accident involving passenger cars 0 = No car involvement 1 = Car involvement
	IstFuss	Accident involving pedestrians 0 = No pedestrian involvement 1 = Pedestrian involvement
	IstKrad	Accident involving motorcycles 0 = No motorcycle involvement 1 = Motorcycle involvement
	IstGkfz	Accident involving heavy goods vehicles (GKVFZ) 0 = No involvement of heavy goods vehicles (Includes trucks over 3.5 tons, tank trucks, or special construction trucks) 1 = Involvement of heavy goods vehicle
	IstSonstige	Accident involving other vehicles 0 = No involvement of other specified vehicles (Refers to vehicles not listed above, such as buses or trams) 1 = Involvement of other specified vehicles (From 2016-2017, includes accidents with heavy goods vehicles; from 2018, excludes heavy goods vehicles)
	USTRZUSTAND	Road condition 0 = Dry 1 = Wet/slippery 2 = Icy
Miscellaneous	LINREFX	Graphical coordinate X (UTM system)
	LINREFY	Graphical coordinate Y (UTM system)
	XGCSWGS84	Graphical coordinate X (GK system)
	YGCSWGS84	Graphical coordinate Y (GK system)
	PLST	Plausibility level 1: Successful plausibility check via standard method 2: Successful check via extended method for bicycle accidents

Appendix C: Survey Statistics from Individual Locations

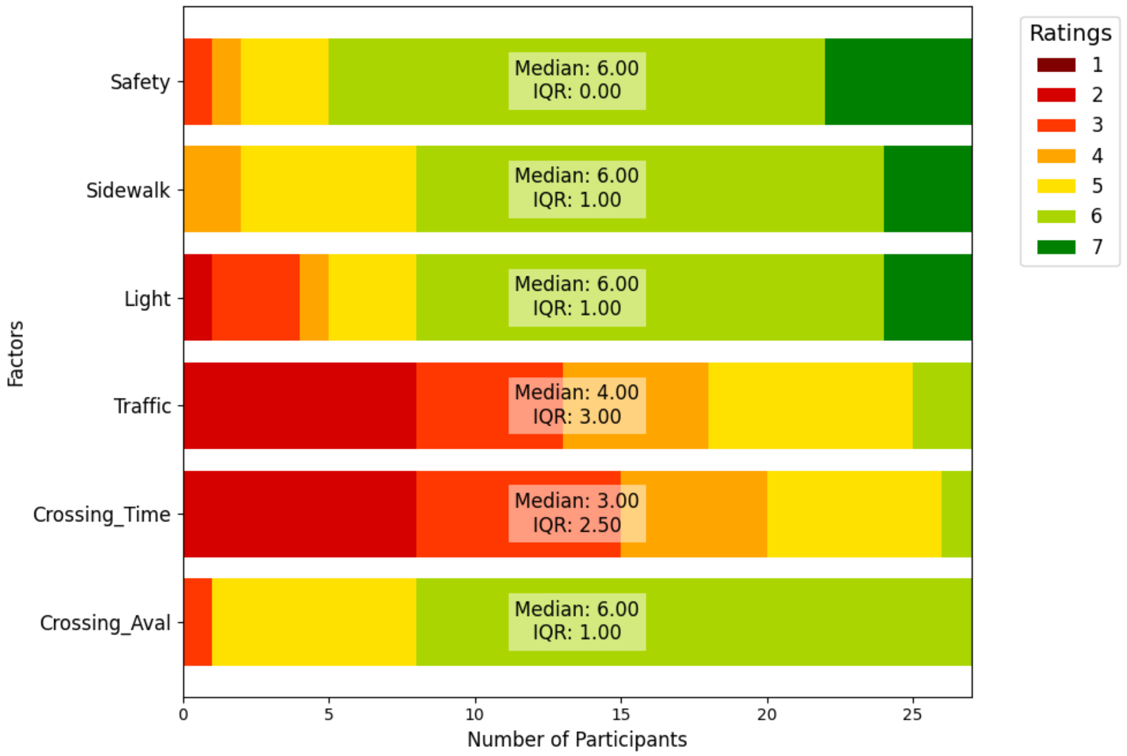

Figure 35 Lerchenauerstraße

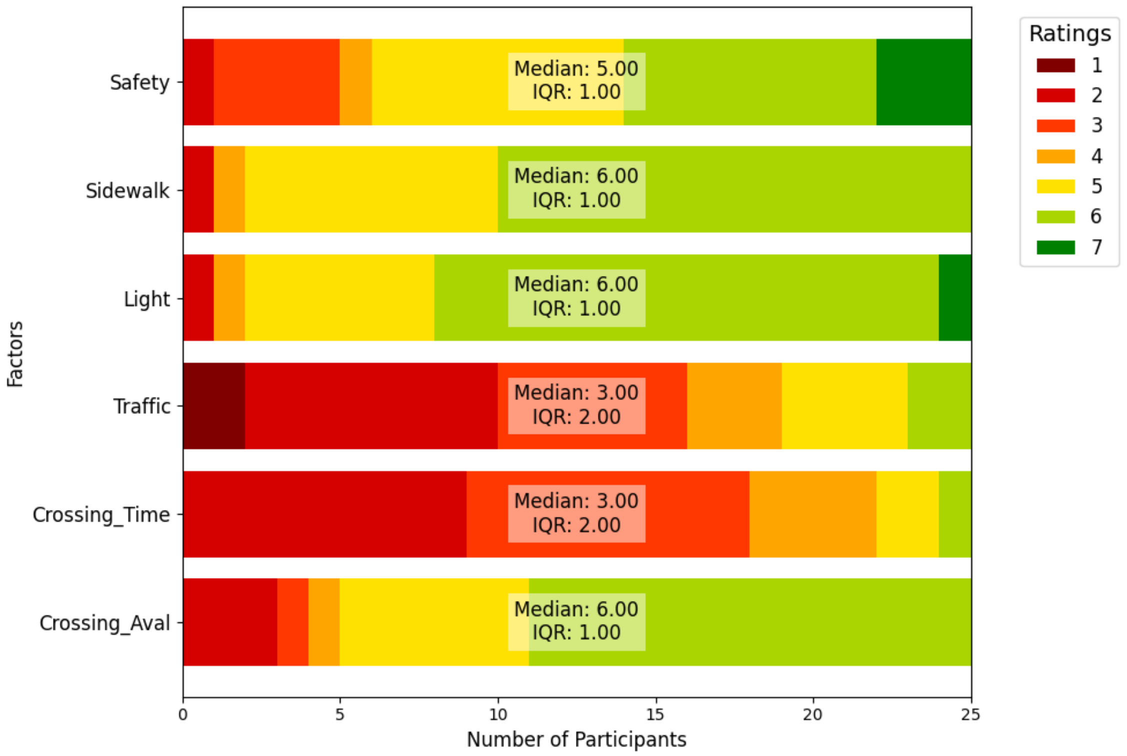

Figure 36 Schleißheimerstraße

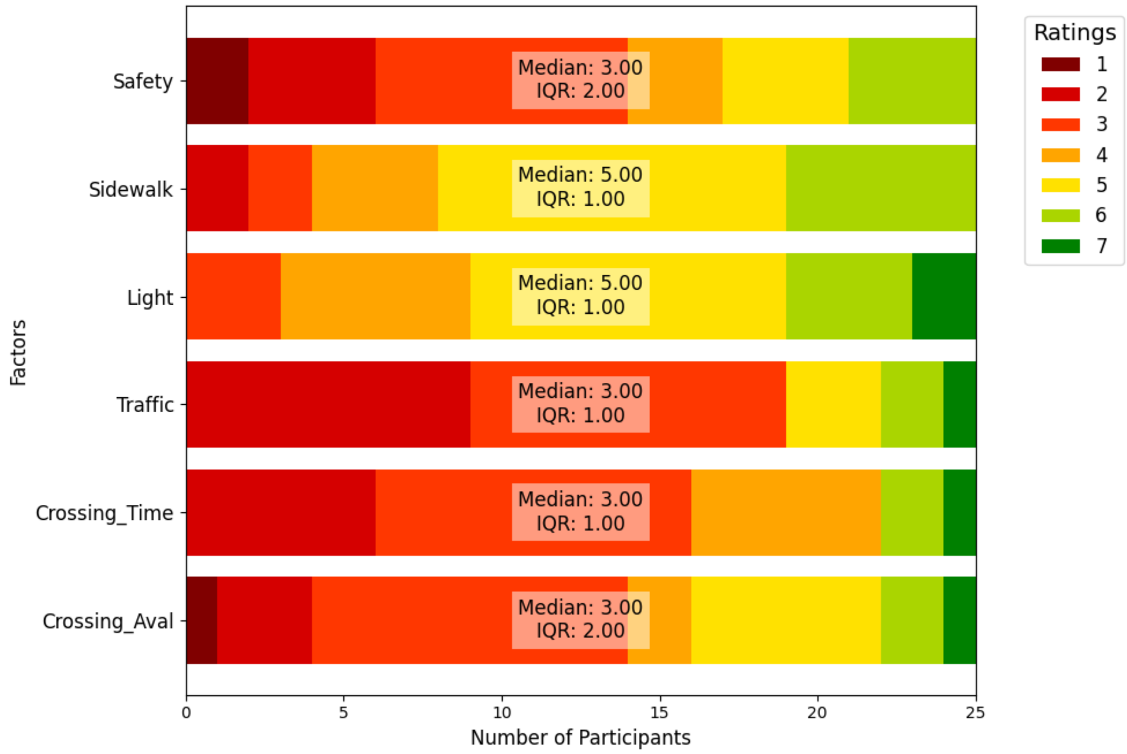

Figure 37 Frankfurter Ring

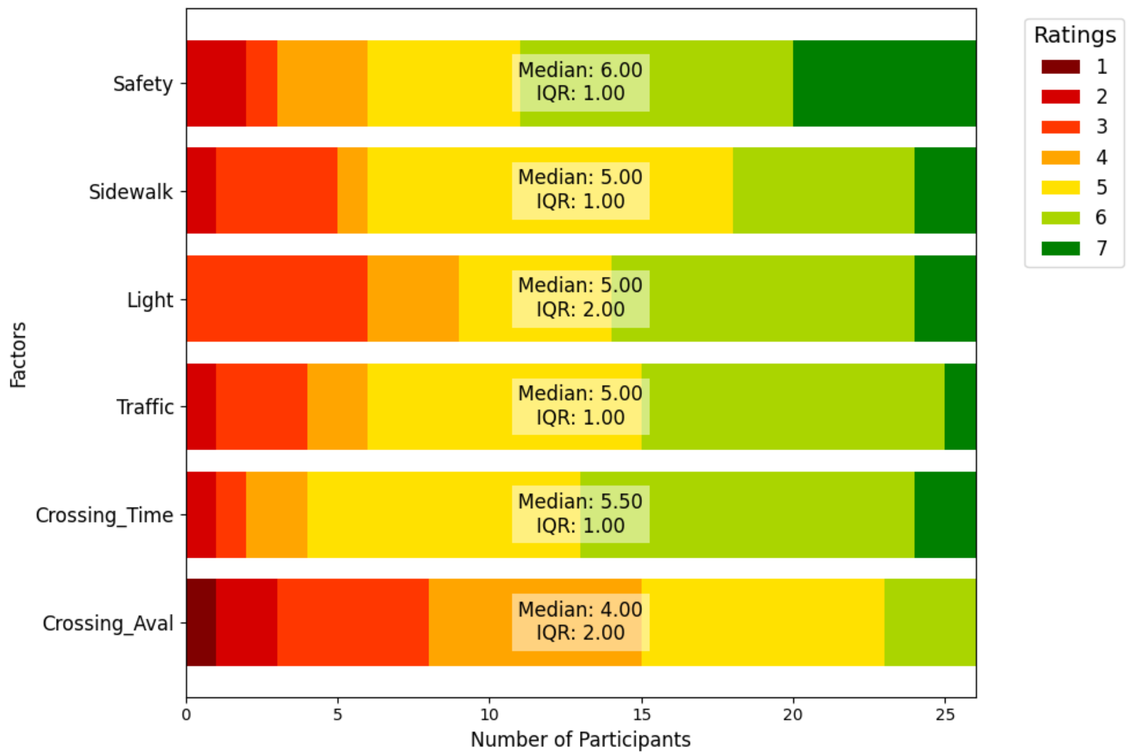

Figure 38 Leopoldstraße

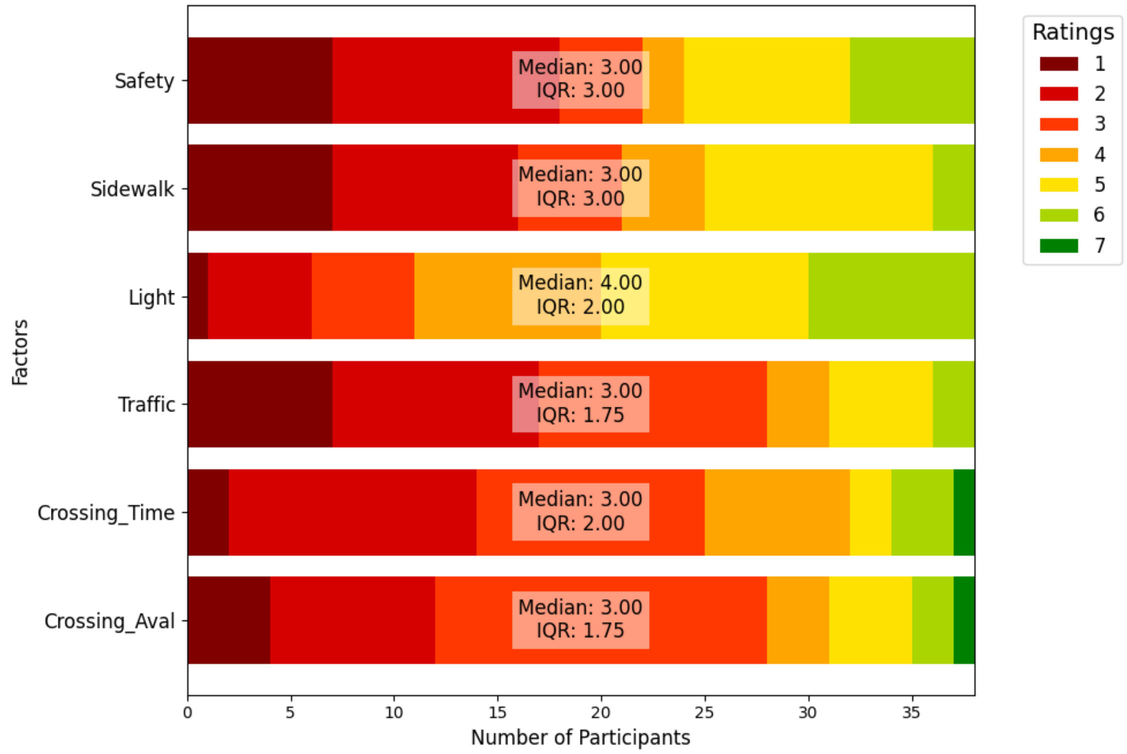

Figure 39 München Hauptbahnhof

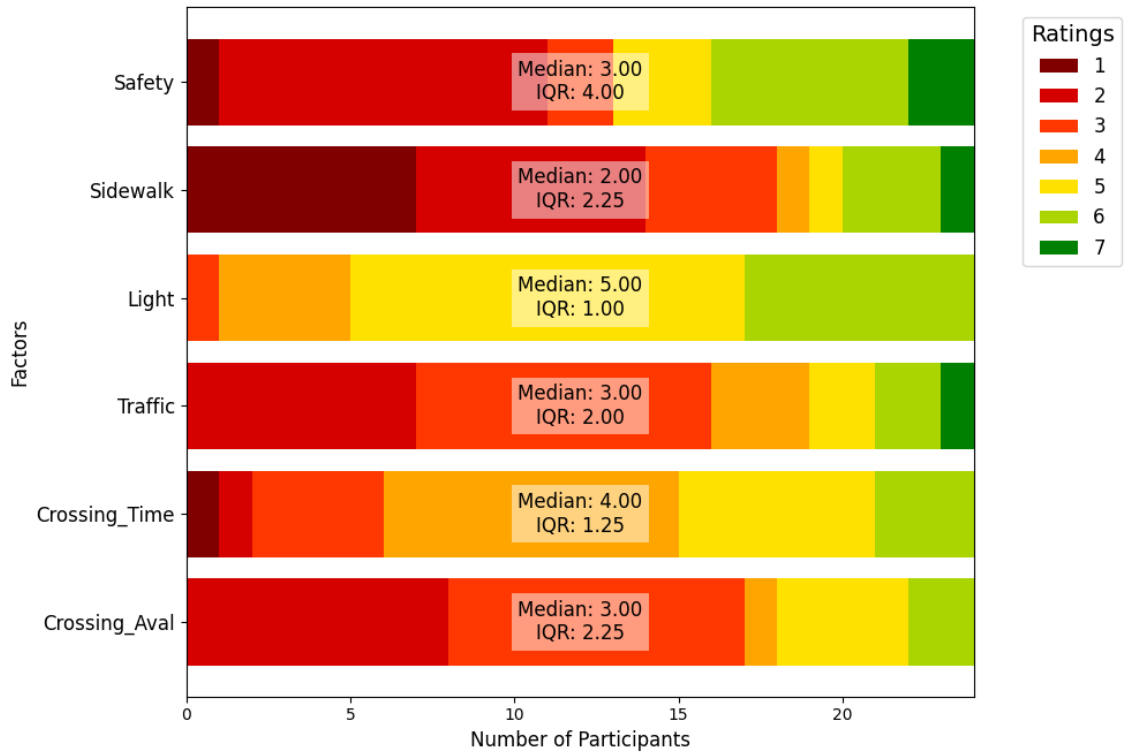

Figure 40 The high-risk segment of Lindwurmstraße

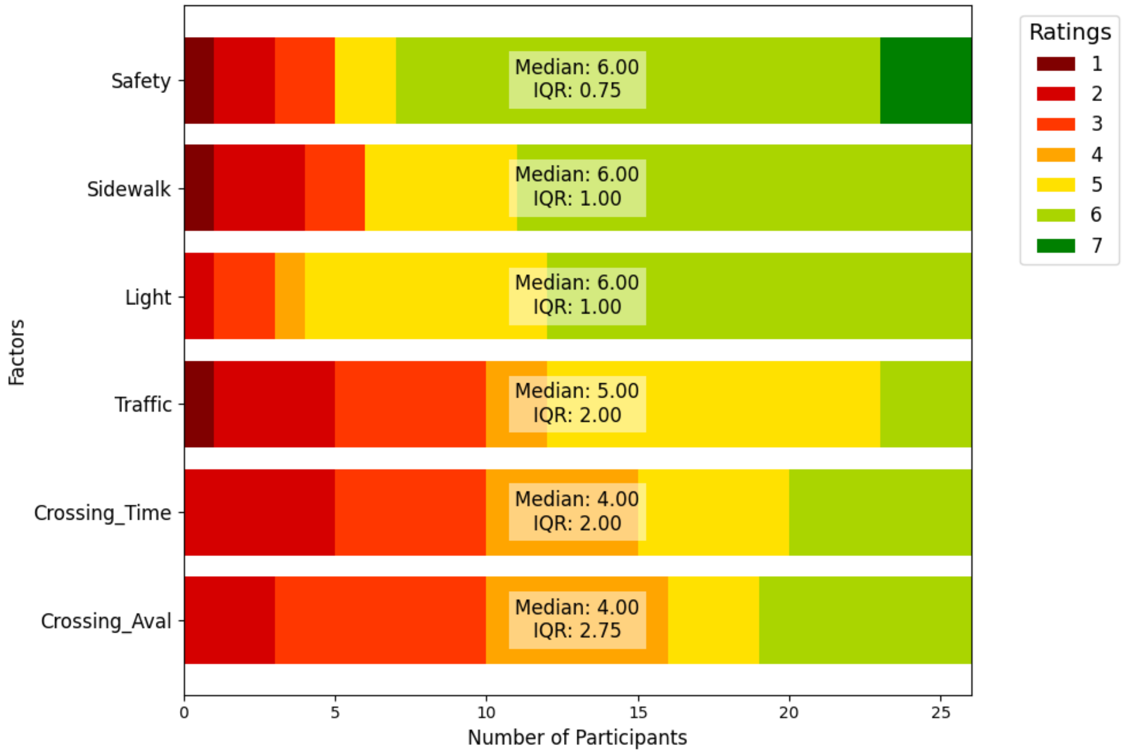

Figure 41 The safer segment of Lindwurmstraße