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THE CONTRIBUTION OF A UNIVERSAL NETWORK ANALYSIS TOOL FOR CYCLING INFRASTRUCTURE

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Acknowledgements

This master thesis is for me more than just a part of the master that I follow, it is the end product of a rich study period with ups and downs. In my bachelor years I have enjoyed, next to the studying itself, the freedom and social aspects of studying and over those years I have had the luck of meeting people that have shaped and inspired me. The Master could best be described as a separate phase in my educational career, since my focus for my study and following career grew strongly in this period. The master in general and this thesis in particular was a challenge that has made me grow and work in ways I could not have imagined a year ago. The thesis, based on one of my main interests, was definitely challenging at times though luckily I have had people that were helping me. First, I would like to thank my supervisor Farzaneh Bahrami for her valuable tips and support. Furthermore, I would like to express my thanks for Samira Ramezani for being the second reader for my thesis. Next to that I would like to thank my parents, Ernie Wijnstekers and Mieke Swaan, for supporting me, without them I would not have been able to be where I am. And some of my friends that have been supporting me, Niels Haveman, Ge Zhu, Lima Dastgeer, Jeroen Beekman, Thomas Amorij and Dakshin John. I hope that reading the thesis conveys the same enthusiasm that I had writing it.

Summary

Cycling is gaining popularity as a sustainable mode of transport for urban mobility. However, best practices for increasing its modal shares in urban context still show inconsistency particularly in the context of cities in developing economies. In these cities in developing economies methods and tools are insufficiently studied.
The aim of this study was to test the applicability and relevance of a tool for cycling infrastructure improvements by Wysling & Purves (2022) from a European context on a city, Bangkok, in a developing nation. Theoretical perspectives described both a wide array of factors to be relevant for increasing the cycling share in urban contexts. Furthermore, this section highlighted the relevance of a shift in discourse based on speed and efficiency to a discourse that presents the wider social context of mobility and therefore cycling.
The methodology of this study is both a case study based on literature as well as an RStudio performed analysis based on an R script developed by Wysling & Purves (2022) that was modified to accommodate the case specific data.
The case study compared two areas, the inner-city of Paris and the inner-city of Bangkok based on factors relevant of population density, slope, area size, public transport and policy. The comparison found no clear reasons for cycling mode shares of inner-city Bangkok not to be able to match those of Paris. The comprehensive policy and tools used in Paris as part of Plan Vélo align closely with most of the best practices outlined in theory and therefore highlights the potential of these methodologies and tools for Bangkok.
One of these tools could be the model of Wysling & Purves (2022) as mentioned before. The variables used in this model were found to be in accordance with similar studies and therefore promising and reliable for the analysis. However, the data requirements of the model were too specific and therefore did not match the data availability for the case area in Bangkok. Subsequently, the model was found not applicable on the case area in Bangkok and universal applicability of the model was not supported by these findings.
This study recommends with regards to the model further modification of the model of Wysling & Purves (2022) to accommodate lower data availability since the model has great potential yet cannot be used universally.

Keywords: Cycling, bicycle infrastructure, mobility, network analysis

List of tables and figures

List of abbreviations

GIS – geo information systems

MAAS – mobility as a service

POI –point of interest

FP – Filtered Permeability

BMA – Bangkok Metropolitan Authorities

1. Introducing cycling in the urban context

Urbanisation, a rising challenge

Increasing concerns on climate change, congestion and motorised mobility related health issues in cities have led to a rise in interest in cycling as a more sustainable means of urban mobility. However, best practices on its implementation still remain underdeveloped (Panthasen, Lambregts, & Leopairojana, 2020; Böcker, Dijst, & Prillwitz, 2013; Larsen, Patterson, & El-Geneidy, 2012). The term sustainability is used in many contexts. In this study the term sustainability is related to the way it can sustain despite the projected challenges of the future within the urban context. In this study the description of Black (1996) for sustainable transportation: *"satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs"* (Black, 1996, p. 151). Current forms of urban mobility increasingly show structural constraints for cities and their future.

Following the definition of sustainability, currently most transportation systems in cities around the world are not as sustainable (Savaria et al., 2021).

This in combination with projections of growing urban populations extends the urgency in urban context. By 2050 the population projected to live in urban settlements is 66% of the by then 10 billion people on the earth (United Nations, 2014).

Climate change will increasingly impact growing populations in urban settings (Masson, Lemonsu, Hildago, & Voogt, 2020). Increasingly cities are required to be more resilient for climate related events. Car oriented development impacts and dominates streets of cities do not accommodate measures to accommodate resilience (Colville-Andersen, 2018). Therefore, the need for a shift to more sustainable mobility is of great importance to the future liveability of cities.

Urban mobility, the movement of people in a city, is something that is essential to cities (United Nations, 2020; Jacobs, 1961). Streets are the networks that allow people to move from one place to another. Urban mobility is not describing a new phenomenon, it is as old as cities are and key to their functioning and of great importance since cities were built near a waterway or major road (Clark, 1958). The mismatch of spatial locations creates the demand for movement, and therefore people and goods travel through the city (Bertolini & le Clercq, 2003). Mobility is a necessity for cities however the distance that people need to travel and how they travel are factors that can be influenced (Bertolini & le Clercq, 2003). The development patterns, especially the layout and spread of cities strongly impact the suitability of different modes for urban mobility.

Health and active mobility, more than just a means of transport

Active forms of mobility like cycling and walking create health benefits since they are next to a means of transport also a form of physical exercise (Capodici, D'Orso, & Migliore, 2021; Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022). A systematic review of publications by Oja et al. has found the following health related benefits related to cycling; improved cardiovascular health, lowered risk of stroke and heart attacks, improved cholesterol levels, reduced risk of type 2 diabetes, improved mental health and brainpower (Oja, et al., 2011). The list contains most of the current diet and exercise related issues that are increasingly prevalent worldwide (Oja, et al., 2011).

Despite the health benefits of cycling, there are also health risks, especially for the early stage of developments of cycling networks. In the initial phase of cycling networks accidents happen more frequently and bad air quality causes health related issues. However, even in this early stage the health benefits far exceed the health risks of cycling (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010). Moreover, in cases when cycling levels rise, injury rates drop. Next to that, with less motorised traffic and more cycling traffic, health benefits increase and health risks decrease (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010). The increase in evidence on the health benefits of active mobility has motivated many authorities to stimulate active means of mobility (Cavill, Kahlmeier, & Racioppi, 2006). On top of this, costs of motorised vehicles have costs far exceeding the direct costs such as petrol and road tax since their contribution to unsafety, air quality and similar societal costs are often not directly paid by the driver. These costs, often referred to as the external costs of mobility, have shown only for active mobility to be beneficial to society (Schröder, et al., 2023).
While this mostly focuses on the physical issues, studies also have shown cycling to benefit social interactions and multicultural understanding. The latter is mostly due to cyclists more interacting with their surroundings.

Why the bicycle?

In the transition of cities for more sustainable means of transport two active means of transport, walking and cycling are the main competitors (Pucher, deLanversin, Suzuki, & Whitelegg, 2012; Larsen, Patterson, & El-Geneidy, 2012; Capodici, D'Orso, & Migliore, 2021). Walking is equally sustainable and desirable as a means of sustainable transport and is the most space efficient. However, this project focusses on cycling. In walking, mankind is already among the more energy efficient animals of the animal kingdom and by far superior to any motorised means of transport however, the bicycle offers mankind an even more efficient means of transport (Illich, 1978). Like walking the requirements for infrastructure are small and it is a cost-effective means of transport. While it carries most of the benefits, active and low carbon footprint, of the walking it offers more efficiency and reach. The greater reach and greater speed of cycling make it more competitive in offering an alternative to current unsustainable means of transport in the urban context (Forsyth & Krizek, 2011; Lovelace, et al., 2017; Fishman, 2016). The bicycle increases the effectiveness of the public transport significantly due to the increase of reach of the bicycle as the illustration in Figure 1 indicates (Kager & Harms, 2017; Capodici, D'Orso, & Migliore, 2021). Next to that, while walking in a combination with an extensive public transport system allows for similar mobility it does not offer the same cost effectiveness and is therefore, for most cities in the world, less desirable (Kager & Harms, 2017; Capodici, D'Orso, & Migliore, 2021; Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022).
Furthermore, stimulation of cycling can indirectly stimulate walking because the measures stimulating cycling often also improve the walking infrastructure and its incentive. Cycling offers a cost effective and efficient sustainable mode of transport that is increasingly popular and is therefore the focus for this project.

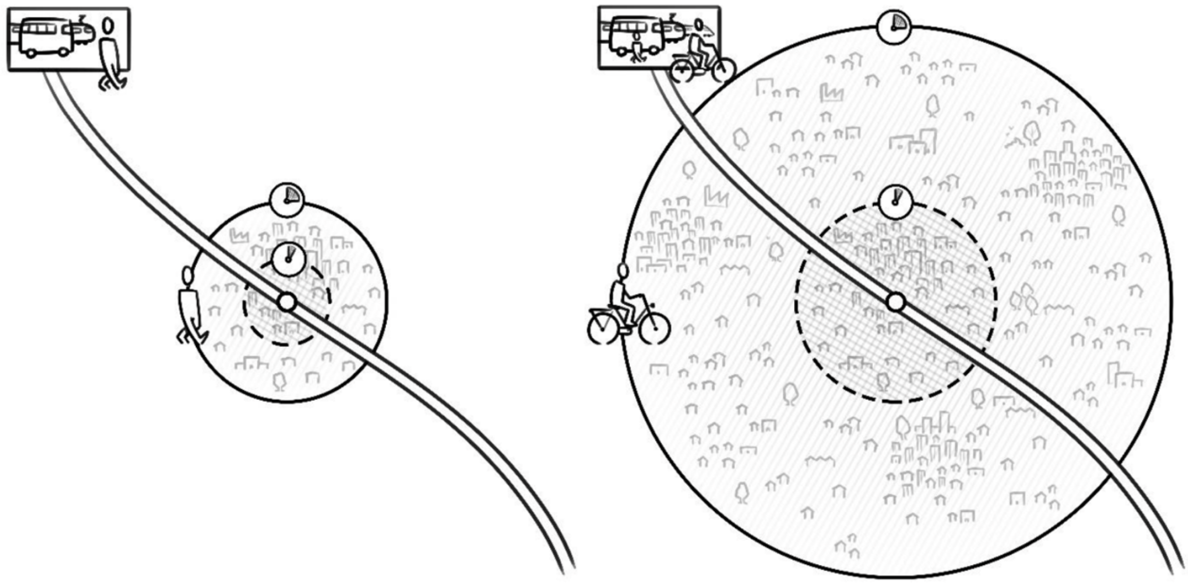

Figure 1: Differences in catchment area for walking and cycling, source (Kager & Harms, 2017)

Popularity of cycling for urban environments

The limitations of the current forms of urban mobility are increasingly gaining awareness allowing for debates on alternatives (Larsen, Patterson, & El-Geneidy, 2012; Capodici, D'Orso, & Migliore, 2021). Growing public awareness about the negative impacts of car-based urban mobility is being related to ecological issues, public health, monetary issues, urban liveability and land use (Savaria et al., 2021). Subsequently, major changes in policies and practices are needed to meet the required changes to offer sustainable mobility (Savaria et al., 2021). As a result, the bicycle is gaining ground as a means of urban mobility since it is inexpensive, healthy and a sustainable form of transport (Milakis & Athanasopoulos, 2014; Cabral, Kim, & Shirgaokar, 2019). Two categories of dilemmas constrain cities in becoming more bicycle friendly. The first is the dilemma that the more sustainable means of transport must match the quality of accessibility, speed and comfort provided by private motorised transport (Bertolini & le Clercq, 2003; Chen & Lu, 2016). The second is that the current social and physical layout accommodates the private motorised vehicle more than sustainable means of mobility. In the considerations of the stimulation of cycling infrastructure in different physical geographical contexts two variables are often given that influence the potential for cycling of a city, the relief and the climate. The relief does play a role in the limitations on human powered vehicles like the bicycle. The second variable, suggested by a literature review by Böcker, was found not clearly showing an effect (Böcker, Dijst, & Prillwitz, 2013). Most literature was found to give fragmented and incomplete indications on the effect of climate on cycling behaviour.

Cities vary in degree to which they can be made more suitable for cycling. While the level of success is dependent on a great variety of variables, cities with a lot of elevation or low density are less suitable since average perceived trip distances are greater than average bikeable distances.

Transition of sustainable mobility, unfortunately an western centred movement

The importance of improving urban mobility in a sustainable way is increasingly on the agendas of cities as many European cities have already been changing their unsustainable urban mobility (Rybarczyk & Wu, 2010).

However, for cities in developing nations shifting from unsustainable means of transport has only in a few cases been successful (Bakker, et al., 2018; Panthasen, Lambregts, & Leopairojana, 2020). As a remark for the entire dissertation, I acknowledge the inaccuracy of the terms "developed" and "developing" nations and economies however for lack of better terminology these terms will be used in further sections. Many cities in developing nations see similar rises in car ownership, therefore the development of alternatives avoiding the path of wealthy nations in car dominance in cities is of urgency (Wright & Fulton, 2005). By 2030, the number of private vehicles of the developing world will exceed that of the developed world (Wright & Fulton, 2005). Bangkok, the capital of Thailand, is one of the cities in developing nations that, despite attempts, has not yet been successful in directing mobility to more sustainable forms (Siridhara, w.d.). It has a build-up area that covers up roughly 40x40 km^2 and has a population of about 10 million. The central area is dense, has little elevation and is generally mixed, in theory favouring conditions for cycling yet cycling rates are low especially for commuting trips (Panthasen, Lambregts, & Leopairojana, 2020). The city of Bangkok is at the same time prone to experience severe effects of climate change (Sintusingha, 2006). Moreover, it struggles with congestion and has limited financial means to develop public transport compared to more affluent cities, strengthening the need for active modes of transport.

The municipality of the city of Bangkok has acknowledged the potential of cycling as a means of transport for the city and aims to stimulate cycling (Bakker, et al., 2018; Panthasen, Lambregts, & Leopairojana, 2020). Several studies have pointed out that Bangkokians are sympathetic towards the idea of cycling or increasing the levels of cycling for utilitarian purposes (Kijmanawat & Karoonkornsakul, 2016; Lambregts & Phanthasen, 2013; Leopairojana, 2016; Panthasen T. &., 2016). Several attempts have been made by local authorities in increasing the cycling share in Bangkok. However, they have not met expectations since the network is incomplete and unsuccessful in increasing the bicycle shares (Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022). The network has been described as fragmented due to a lacking governmental holistic approach of the network with cohesive policy covering the wide array of required changes (Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022).

Promising case of Paris and challenges for Bangkok

The remarkable improvements that Paris has achieved since 2015 due to the introduction of Plan Vélo, a cycling stimulation plan, has attracted attention from many authorities and academics. Much of the cycling network has been guided by geo data combined with a wide scoped policy. A promising geodata based assessment technique based on the bicycle transition of Paris was developed by Wysling and Purves (2022). This technique promises universal applicability as it is based on easily available open-source data for providing the guidance on the development of cycling infrastructure. Thereby it can support decision making and policy for sustainable mobility transitions. This model, however, has only been tested on the inner city of Paris. For this project the cities of Paris and Bangkok will be studied to compare the bicycle related infrastructure and context in which these were created. The current form of mobility in Bangkok is showing its structural constraints such as major congestion, low air quality and climate effects severely impacting its liveability. The methods of Wysling & Purves (2022) promise to offer a valuable contribution to the planning and decision making of cycling paths for cities in different geographical contexts.

Facilitating cycling, from sectionally to holistically

Cities with high bicycle ridership have shown promising results and receive increasingly attention however methods of achieving increases in bicycle ridership are still not fully developed (Panthasen, Lambregts, & Leopairojana, 2020; Pucher, Infrastructure, programs, and policies to increase bicycling: An international review, 2009; Rybarczyk & Wu, 2010).
The implementation of small sections of infrastructure has been proven to be ineffective because cycling infrastructure requires a critical mass in the shape of a network (Gerike & Jones, 2015; Cooper, 2017; Cabral, Kim, & Shirgaokar, 2019). Approaches that treat the bicycle network holistically have been advised for effectively reaching the critical mass and beyond (Rybarczyk & Wu, 2010; Cabral, Kim, & Shirgaokar, 2019). In many cases however cities struggle in ways to implement cycling networks holistically. In many cases shoehorning the cycling infrastructure in the existing urban fabric results in fitting the bicycle lanes in space contests with private motorised vehicles and therefore conflicts often arise (Parkin & Koorey, 2012; Cabral, Kim, & Shirgaokar, 2019).
Therefore, the methods of developing complete cycling infrastructure networks in cities where road space is dominantly focused on private motorised vehicles relevant (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010).
Specifically targeted planning in the development of cycling networks that provide safe, efficient access for complete trips between frequent origin and destination locations is needed (Larsen, Patterson, & El-Geneidy, 2012).

Contributing methods to support the development of cycling infrastructure and their large-scale networks is important to transform towards more sustainable forms of urban mobility (Cooper, 2017; Cabral, Kim, & Shirgaokar, 2019). Specifically citywide implementation of bicycle infrastructure catering for existing as well as potential cyclists is needed (Cooper, 2017).
Connectivity of the sections of the network is of priority, both for directness and even more for safety since that is the most important determinant for residents to cycle (Cabral, Kim, & Shirgaokar, 2019).
The use of geodata to plan cycling networks holistically can be promising though as Larsen mentioned there is not much research into the abilities and methods of using Geodata to work on cycling network development (Larsen, Patterson, & El-Geneidy, 2012; Rybarczyk & Wu, 2010; Cooper, 2017).
Despite this, methods developed by scholars have shown promising results when using geo data in analysis of current cycling networks as well as developing potential effective improvements (Rybarczyk & Wu, 2010; Wysling & Purves, 2022; Capodici, D'Orso, & Migliore, 2021). Though, as some studies also have noted, a network based analysis of the development of cycle paths is only one of the many components of cycling promotion (Wysling & Purves, 2022; Handy & Xing, 2011; Lovelace, et al., 2017; Capodici, D'Orso, & Migliore, 2021). Other factors, both physical as well as social, influence the success of cycling modal share in cities (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010).

Aim of the study

The urge of making urban mobility more sustainable and the methodology of its implementation is the wider context of this study. More specifically, this study focuses on increasing the attractiveness and safety of cycling through its infrastructure in this context. While cases in Europe reach promising results on increasing the cycling share, developing nations have little success. Best practices and methodology for the implementation are incomplete and in development. Perceived safety is one of the key factors impacting the chances of people cycling and the implementation of good cycling infrastructure is one of the key methods of achieving gains in perceived safety. Cycling infrastructure is effective yet is often one of the difficulties in cycling stimulation, especially in the early stage in the implementation. A model developed to effectively steer the implementation of cycling infrastructure was developed by Wysling & Purves (2022) claiming general applicability and therefore was tested on Bangkok.

This bicycle infrastructure network analysis model has the potential to be a successful tool for the case area of Bangkok yet the wider context and its relation to the original case area of Wysling & Purves (2022) is also relevant for its applicability.

The aim of this study was to test the applicability and relevance of a tool for cycling infrastructure improvements by Wysling & Purves (2022) from a European context on a city, Bangkok, in a developing nation.

Research question

Can the model developed by Wysling & Purves (2022) for Paris be applied to other cities?

The main research question will be answered by the following sub questions:

- What theories are relevant in directing the interventions of cycling infrastructure for cycling in urban contexts?
- What is the current stage of development of cycling in Paris and Bangkok?
- To what extent is the model of Wysling & Purves (2022) applicable to the context of central Bangkok?

The case areas, Paris and Bangkok, where expected to be comparable in for the model relevant variables yet deviate in its policy and use of tool as a means of increasing cycling rates. While methods to enhance cycling in the urban context are wider than the model, the model of Wysling & Purves (2022) is assumed to give a valuable contribution to the analysis of the cycling network in Bangkok since it is based on strong variables in assessing cycling routes and uses reasonably accessible data.

The structure of this study

In this study, first a theoretical background is given to elaborate on the choices made in developing cycling networks. The framework is relevant to this study because the scope and criteria chosen impact the choices made in the analysis and the way the data is interpreted. Furthermore, the framework will discuss the capabilities of geodata analysis and its recent rise in interest as a way to guide the developments of cycling infrastructure networks.

This is followed by a case analysis of cycling in the region of south-east Asia to put Bangkok in the perspective of regional developments in cities on cycling integration.

Following that paragraph an analysis of the case area of the study of Wysling & Purves (2022) in Paris is made succeeded by an analysis of the case area of Bangkok to analyse the cycling model-oriented comparability of the two case areas.
In the methods section both the methods of the paper of Wysling & Purves (2022) as well as the adaptations that were needed for the analysis for the case area in Bangkok is described. This is followed by a results section that will describe the process of the analysis and the findings.
Finally, the results and the implications will be discussed in the discussion and conclusion section.

2. Theoretical perspectives on the implementation of cycling infrastructure

Introduction to theoretical perspectives on cycling enhancement

The many forms of cycling networks seen in cities around the world indicate a complexity that this section aims to explain and thereby create a theoretical frame for the case analysis and for the model of Wysling & Purves (2022).

Increasingly the complex societal and social nature of mobility is being studied revealing a wide level of choice that is relevant to mobility. These findings create more understanding on the choices and how problems in mobility are framed. While both Paris and Copenhagen show successful outcomes in terms of cycling rates their methods differ greatly. For Bangkok and similar case areas the methods for reaching similar goals in cycling rates to European cities might differ in some aspects while might be the same in others. Therefore this framework will explain the factors and their varying applicability relevant to cycling stimulation for cities starting from a low cycling share like Bangkok.

This paragraph first will discuss for “what” is planned. After that the “where” is discussed, as there are theoretical considerations to where to build cycling infrastructure. The “how” will be discussed thereafter and will elaborate on discourses of mobility.

Several phases on cycling research have emerged since the 1990’s in different parts of the world (Larsen, Patterson, & El-Geneidy, 2012; Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010; Pucher, Infrastructure, programs, and policies to increase bicycling: An international review, 2009). Larsen et al. distinguished four streams in the literature on cycling infrastructure (Larsen, Patterson, & El-Geneidy, 2012).

The first stream focuses on the cost benefit analysis of cycling on society, a financial scope that often shows the great amount of benefits as opposed to motorised means of transport (Hopkinson & Wardman, 1996; Ortuzar J, 2000; Krizek, 2007).

The second and largest stream aims to provide a better understanding on how different facilities and environmental factors, especially cycling infrastructure, affect cycling behaviour. Cycling levels per city vary greatly world-wide and a complex set of variables influences these levels. Some variables, as some authors have noted, are hard to change like a great amount of relief in cities. Relief impacts the reach of active forms of transport since they rely on its user for its movement. Smart combinations with public transport can however overcome some of the limitations of hilly cities.

The third stream of research is aimed at providing knowledge on what other factors aside of cycling infrastructure influences the attractiveness of bicycle usage in cities (Handy & Xing, 2011; Noland, Deka, & Walia, 2011). A variety of literature provides insight in both hard measures such as increasing bicycle parking facilities and reducing road speeds as well as soft measures such as providing cycling education and increasing cultural appropriation (Najdovski, w. d.; Fenu, 2021). The fourth and last stream of literature is mostly focussing on the safety issues related to cycling facilities. This category focuses on different elements of cycling networks that are analysed in the way they prevent accidents from happening.

2.1 The What, type and functions

Different types of cyclists; recreational and utilitarian

Cyclists can be categorised in a variety of types of cyclists, though for the purpose of this research the distinction by purpose of recreational and utilitarian cyclists is used. This categorisation is commonly used in policy and research due to their strongly differing needs in terms of cycling infrastructure.

A network related to recreational cyclists is usually not oriented on origin destination logic but rather at aesthetical qualities since the purpose is the travel itself and not the reaching of destinations. In most urban applications, this includes infrastructure that is built in parks or other green spaces. In other contexts, it refers to infrastructure connecting cities and tourist destinations for recreational purposes.

Utilitarian cycling trips are necessary trips, for instance for commuting and doing groceries. These trips have clear origins and destinations compared to recreational trips and focus less on the aesthetic qualities of the context of the infrastructure.

Research concerning sustainable urban mobility is mostly aiming at utilitarian trips as they make up for the largest share of trips and are most frequently done by car. This category is also the most demanding when it comes to infrastructure.

Different modes of transport, different purposes; where does the bicycle fit?

The bicycle is not the solution to all mobility demands, since its success is context dependent (Bertolini & le Clercq, 2003). In an analysis on the metropolitan area of Amsterdam two main variables categorising contexts dependent potential of different modes of transport were described by Bertolini and Clercq. A conceptual framework was developed by Bertolini (2003) wherein two main variables were indicated to characterise types of modes of transport and their applicability to different spatial contexts. The first one is

Spatial reach of an activity or function, indicating the ease of travelling distances (Bertolini & le Clercq, 2003). And the *Intensity of use,* which, in the context of modes of transport, means the number of movements in an area. As described by Bertolini, the different means of transport each have their effective position in offering mobility as can be seen in Figure 2. The analysis revealed that cars have a great reach and can be viable in low trip density areas. However, the car is least suitable in areas with high trip density due to its relatively large claim on space. In urban contexts spatial reach is rarely a limiting factor. The trip intensity though, the demand for trips in a given area, is a factor that plays a vital part as shown in Figure 2. Public transport can accommodate large trip distances though is limited in flexibility and requires a threshold and is therefore suitable between and within cities though relies on other means to connect from door to door. Walking and cycling are least suitable for long distance travel however offer great flexibility and due to their relatively small footprint are suitable for areas with high trip densities. Therefore, the research advocates the use of cycling and walking in combination with public transport as ideal competitor to car mobility which is described as not suitable for inner city traffic. For this study, these findings are of an important nature as it locates the possibilities within the urban context but neither advocates the completely banning of private automobiles in urban context nor does it position the bicycle as a suitable means of transport in low density areas. Since this study focuses on the inner-city areas, where according to the theory of Bertolini the Spatial reach is limited and the intensity of use is high the bicycle can be valuable in offering an alternative for private motorised vehicles.

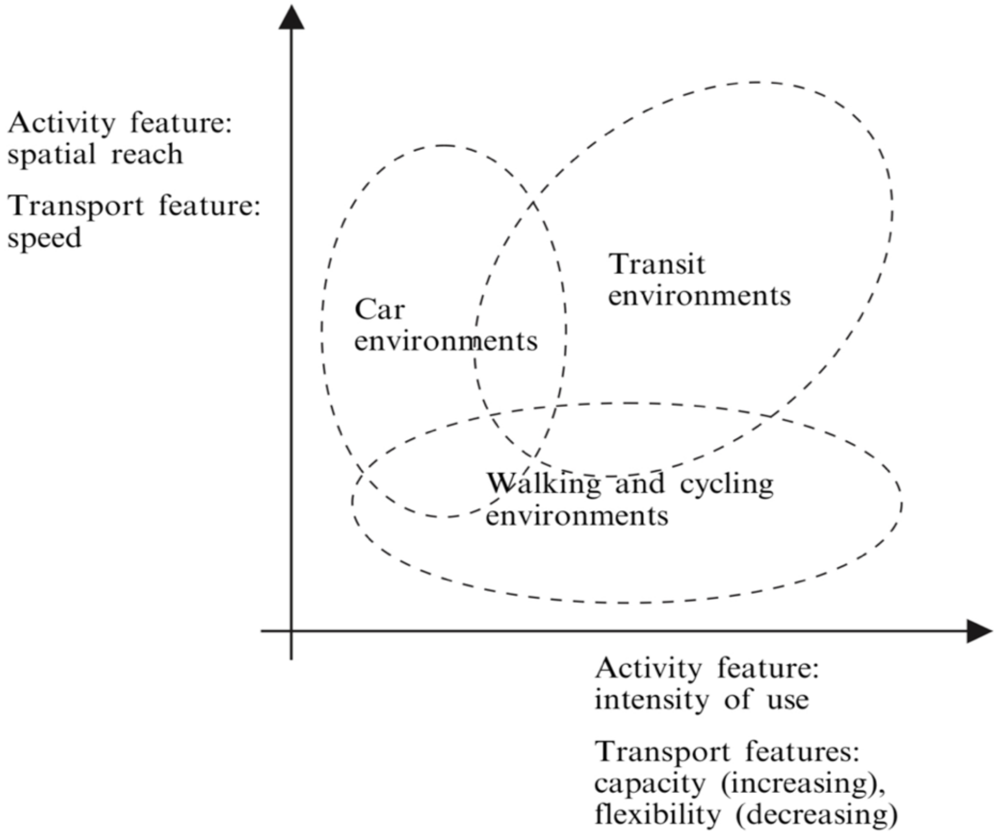

Figure 2:Principles of multimodal urban - regional development: conceptual scheme; source (Bertolini & le Clercq, 2003)

The last mile, the bicycle and its integration with public transport

Synergies of public transport and cycling have the potential to overcome limitations of either of the modes combining the strengths and flexibility offered by each (Kager & Harms, 2017; Capodici, D'Orso, & Migliore, 2021). Motorised traffic offers greater reach compared to walking or cycling while it offers greater flexibility than public transport (Capodici, D'Orso, & Migliore, 2021). As Bertolini described, in low-density areas the private automobile is hard to replace, however there is potential in higher density areas for the bicycle and public transport (Bertolini & le Clercq, 2003). In planning bicycle infrastructure the integration with public transport is increasingly being favoured as projects often provide parking facilities for bicycles near public transport hubs (Kager & Harms, 2017; Capodici, D'Orso, & Migliore, 2021). A study in the Netherlands found the effect of synergies of public transport and cycling to be especially effective in areas that are harder to reach with other means of transport as shown in Figure 3.

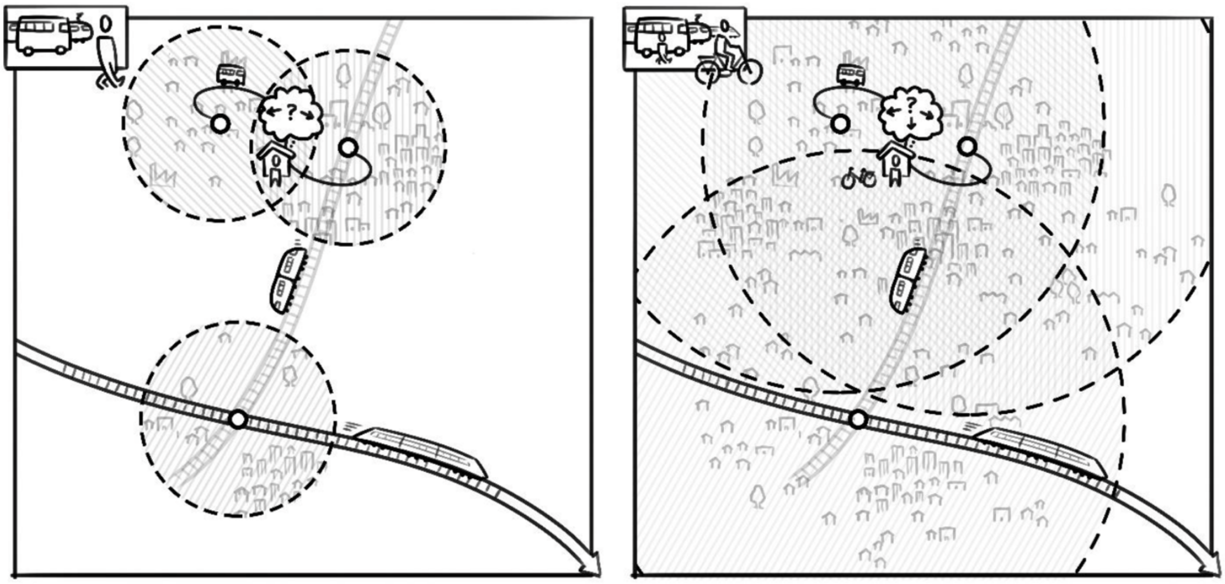

Figure 3: increasing competitiveness of public transport due to increased reach and customisation source (Kager & Harms, 2017)

Furthermore, this synergy next to being effective in offering a viable option to the private car, has many other benefits such as the improved flexibility of route choice and the liveability of transport hub areas as illustrated in Figure 4. In the route flexibility shared mobility often plays a vital part, though this will be discussed in the section hereafter. These networks work best in transit-oriented development of urban areas that are a facilitator and a product of public transport cycling synergies (Capodici, D'Orso, & Migliore, 2021).

Research highlighted the process of induced demand in public transport stimulation, the more the system is used the more attractive the system becomes since frequency and coverage of public transport rely on its ridership.

The synergy of active means of transport and public transport is an important component in designing cycling infrastructure resulting in large scale implementation in cities beyond the boundaries of cities in developed nations (Marqués, Hernández-Herrador, Calvo-Salazar, & Garcia-Cebrián, 2015; Kager & Harms, 2017; Pucher, deLanversin, Suzuki, & Whitelegg, 2012; Bertolini & le Clercq, 2003).

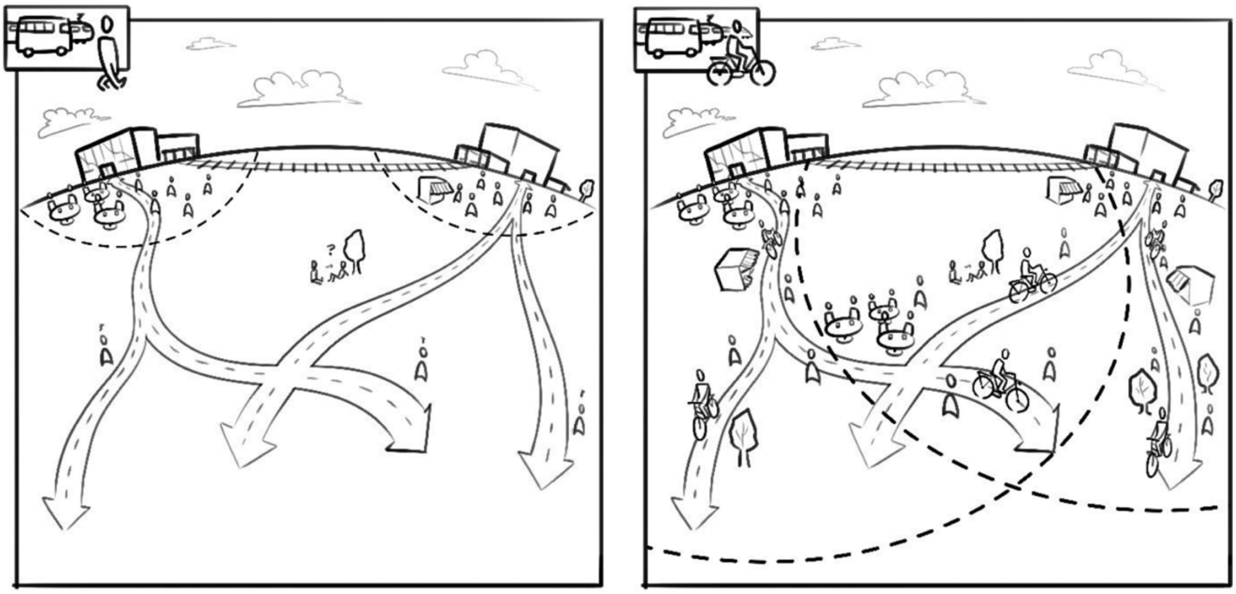

Figure 4: Increase of liveliness in public space source (Kager & Harms, 2017)

Mobility As A Service

The system of shared mobility, often in literature called Mobility As A Service (MAAS), is increasingly being implemented with bicycles in cities (Capodici, D'Orso, & Migliore, 2021). Important developments in IT gave rise to the possibilities of rideshare mobility and resulting interest of authorities. The modes range from rental steps, regular bikes, e-bikes to electric scooters and shared cars. They allow for a wide choice of means of transport and location, in origin and destination, as also described by Kager (Kager & Harms, 2017). While in many cities the systems attracts decent ridership numbers its success is not a guarantee since the bikeability impacts the success greatly.

A second point of critique is to what it provides a solution to, as is frequently the case with new technologies in mobility. Pandey et al. points towards the possibilities of ridesharing to reduce congestion as a main benefit however this is not always the case in practice (Pandey, Monteil, Gambella, & Simonetto, 2019). Rideshare practically often involves multiple companies offering services increasing the number of vehicles. Next to that, it can also increase the number of trips since it can offer an alternative for public transport or can increase the demand for trips. As some of the services are relatively expensive, they don't solve mobility for all.

In the case of commercial companies providing the services the mobility may not be provided on the long term as these companies might change plans or fail. This can result in people losing the mobility they rely on (EIT Urban Mobility, 2022). The MAAS is often included in cycling stimulation plans in cities even though it has drawbacks. While they could play an important role in the stimulation of cycling in urban contexts, they are not included in the parameters of the model of Wysling & Purves (2022). The impact of MAAS, while potentially relevant for models, is beyond the scope of the cycling network analysis by Wysling & Purves (2022).

2.2 The Where, and where to start?

Regaining the streets in cities for people

High density areas like cities have limited space available for movement yet its mobility is also characterised by short average trip distances. Traditionally the streets were multi-function public spaces where people would mingle, play and trade. The introduction of the car changed the network of streets and even shaped cities. Gradually streets transformed into throughways for motorised traffic with subsequent logic. As Illich described traffic, that is the movement of people outside of their front doors, became increasingly dominated by transport. Transport is described as a means of transport that relies on a source of energy, and this type became increasingly dominant in the streets at the cost of transit, human power movement (Illich, 1978). This increasingly made streets unsuitable for anything other than motorised vehicles. Subsequently, supply and demand for car infrastructure paved the way for these car-oriented developments with a short-term focus as the following quote on the counterproductive effect of building roads to solve congestion indicates:

> *"A simple and fundamental principle of economics is that consumption increases as goods become more attractive to the consumer. If transportation is viewed as a consumable good, then transport infrastructure will partly determine its attractiveness to the potential user" (Pfleiderer & Dieterich, 1995, p. 29)*

This quote describes the ineffective method of increasing the capacity of car roads to solve congestion in urban contexts. Cities cannot solve congestion by building more road surface since this will increase the attractiveness of car commutes and therefore causes the congestion to continue only with more cars than before. Currently, authorities are starting to rethink the value of streets and mobility in the urban context paving the way for changes in mobility and its public space. In this the streets become more than spaces to accommodate mobility to places that have value as a public place and a community. Many scholars have noted the traffic reductions as a result of the covid pandemic to be a significant factor in opening up the debate on different values for streets and therefore mobility in urban contexts (Buehler & Pucher, 2021; Moran, 2022; Kraus & Koch, 2021). Therefore, rather than accommodating the private motorised vehicle it is increasingly filtered out of urban traffic.

Filtered Permeability of a city, an indicator or a guideline?

Cities with high cycling shares often coincide with a high modal filtered permeability, the filtering character of the infrastructure based on mode share (Savaria, Apparicio, & Carrier, 2021). This method selectively filters by urban design categories of modes of transport and restricts selectively their accessibility to distinct zones therefore influencing the attractiveness of each type of mode. Making the desired mode of transport in terms of policy outcomes the best option for the public is key. Savaria et al. (2021) defined FP as:

> *"In summary, FP measures allow us to create an urban environment more conducive to cycling by providing shorter routes for cyclists compared to motorists." (Savaria, Apparicio, & Carrier, 2021, p. 2).*

The FP can also increase the comfort and safety of the cyclist as they help reduce the volume and speed of motor vehicle traffic and therefore influence cycling rates and attractiveness (Scherpers, Twisk, Fishman, Fyhri, & Jensen, 2017).

In a study the accessibility of cars to the infrastructure networks of cities was compared to the accessibility of the network for bicycles revealing that in European cities the level of freedom bicyclists has compared to a motorist was on average 44% higher (Savaria, Apparicio, & Carrier, 2021). In a yearlong case study on the FP measure in London the amount of cycling had been analysed to examine the effects of FP on cycling rates. The study found a positive correlation between the two variables, an increase of 24%, on the amount of cycling after the measures were implemented (Aldred & Croft, 2019). In making the routes shorter and the streets accessible to cyclists greater than for cars, the attractiveness is steered both by directness as well as safety.

To effectively increase the modal shares of cycling, the focus should not only be on expanding the kilometres of cycling infrastructure but also on considering filtered permeability for successful implementation, as emphasized by Savaria (Savaria, Apparicio, & Carrier, 2021).

Filtered permeability is an important factor influencing cycling levels, especially to cities that have a low FP and are dominated by car traffic as is often the case for cities in developing nations.

The best route

In most infrastructure there is a focus on either large, motorised traffic as the car or pedestrian related design leaving out cycling specific design (Forsyth & Krizek, 2011). Urban planners have extensive knowledge on how to design for pedestrians, catering in specific demands that pedestrians have in an urban context. On a larger scale, the design and layout of car infrastructure planning has also been well documented. Guidance on cycling in differing contexts often is based on characteristics of either motorised vehicles or pedestrian while cyclists have their own demands on the design of the urban public space (Forsyth & Krizek, 2011). In the Netherlands, by many regarded as a cycling oriented country the logic of policy and infrastructure in many ways is oriented towards either the car or the pedestrian (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021).

Despite bicycle infrastructure being there its layout, facilities and design are not developed from the perspective of the bicycle and therefore require attention in the development of cycling infrastructure (Forsyth & Krizek, 2011)

In an analysis of the potential of bicycle infrastructure the limitations of distance are especially important to consider when planning for bicycle infrastructure. Bicycles are human powered vehicles and as the average capabilities on distances are limited so is the reach. Therefore, in cities where amenities are widely spread out and functions are spatially segregated the implementation of bicycle infrastructure is limited in its potential. The electrically assisted bicycles, e-bikes, can widen the average reach of citizens and thereby make the bicycle a competitor with other means of transport for longer distances. Literature is increasingly describing the benefits but also the limitations of e-bikes. Higher prices of e-bikes makes their accessibility limited to more wealthy residents and creates higher chances of theft. This requires the implementation of safe storage facilities such as **Error! Reference source not found.**.

Next to that, in many applications the use of standardised measures, creating homogeneity in the cycling networks are favoured as this increases the chance of success of the network adding to the benefits of using a network-oriented model (Marqués, Hernández-Herrador, Calvo-Salazar, & Garcia-Cebrián, 2015).

The development of cycling infrastructure networks often involves modelling potential trips to analyse where improvement is made most effectively. Most of these methods have been based on techniques used for cars, using the shortest or fastest route as the most likely. While bicycles are human powered and therefore limited in reach, travel data has revealed that cyclists often deviate from these assumed routes based on speed and distance (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021). Deviations from these expected paths are partly explained by the variables of slope and perceived safety since these are more relevant to cyclists (Broach, Dill, & Gliebe, 2012). Furthermore, the type of infrastructure also strongly influences the choice of route, especially relevant are dedicated cycling paths in this category.

Moreover, research has shown that, since cyclists often are more aware of their surroundings, they are impacted by the aesthetic qualities for their route choice. Using data on these variables in assessing bicycle friendliness of routes in cities is not common, however very important as this can improve the effectiveness of the implementation of bicycle infrastructure.

However, including subjective attractiveness of the routes is currently not possible as data and methods on this variable are scarce and therefore will not be used in this analysis. Milakis and Athanasopoulos have advocated for the use of the local residents in decision-making on where and how cycling infrastructure needs to be implemented with GIS (Milakis & Athanasopoulos, 2014). The analysis showed that residents preferred residential streets above the arterial roads despite current cycling networks more frequently following arterial roads since they offer directness (Milakis & Athanasopoulos, 2014). The importance of making the network safe and orienting it on what is desired rather than following the logic of the shortest route is valuable in developing bicycle infrastructure networks. While currently data on cycling route choice is scarce and therefore prediction models lack accuracy, future data on the route choice of cyclists can offer valuable contributions to the modelling and therefore the development of ideal cycling networks (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021; Wysling & Purves, 2022).

Cycling safety and the role of infrastructure

In the development of cycling infrastructure, the safety of its cycling routes is of importance since it is the key determinant for people to cycle and cyclists are vulnerable road users in environments dominated by motorised vehicles (Cabral, Kim, & Shirgaokar, 2019). Worldwide the eighth largest cause of death is accidents in traffic and since cyclists and pedestrians are most vulnerable in traffic it is of priority to take their safety and thereby prevention of traffic accidents seriously. For cities in developing nations, traffic related casualties are especially high compared to cities in developing countries and therefore providing safety of even greater importance. The perceived safety can be a decisive factor for potential cyclists in their decision to cycle. The Netherlands, known for the highest cycling levels, scores in the top 20 of least traffic deaths per 100.000 in the world therefore high cycling levels do not cause high traffic casualty despite the increase in vulnerability of the mode of transport (International Transport Forum, 2022).

In early stages of the development of a cycling network cycling is at its most dangerous since the number of cyclists are rising while the infrastructure and culture is not yet adapted to protect cyclists from the dangers of other means of transport. An established theory called *Safety by the Numbers* partly explains the lower accident rates in countries that have high cycling numbers (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010).

This concept describes the process relation of when more cyclists participate in traffic, their visibility and therefore safety increases. On top of that, the higher the cycling share the more likely car drivers are frequently cyclists themselves and therefore are more aware of cyclist vulnerability.

While multiple factors have been contributing to the high cycling rates in the Netherlands, cycling safety has been shown to be one of the main factors (Schepers, Twisk, Fishman, Fyhri, & Jensen, 2017).

The idea of cycling safety depends on the protection from cars, as numbers indicate that over 60% of cyclist's fatalities involving a car and 20% public transport despite rigorous measures to prevent this from happening. Moreover, the perceived sense of safety is of great importance as it is an important variable predicting cycling numbers and an important focus for cycling policy. Frameworks, like the Level of Traffic Stress (LTS) and four types of cyclists of Geller have been focussing on cycling safety as the main determinant for the use of cycling infrastructure (Cabral, Kim, & Shirgaokar, 2019; Geller, 2007). The LTS framework allocates levels of perceived safety to cyclists based on a set of variables related to traffic stress to road segments.

The framework by Geller classifies four types of (potential) cyclists (No Way No How, Interested but Concerned, Enthused and Confident, and Strong and Fearless) that have been empirically tested and found to represent adequately the American population (Dill & McNeil, Four types of cyclists? Examining a topology to better understand bicycling behaviour and potential, 2013; Dill & McNeil, Revisiting the four types of cyclists, 2016). These two frameworks help to shed light on the complex assessment of cycling safety and have as a result been used frequently in analysis.

Studies on cycling accidents have found that cyclists are most likely to have an accident on intersections, therefore the focus on intersection design is important in the development of cycling infrastructure while it is often one of the elements that is left out in cycling infrastructure designs (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010).

Beginning of the transition meets resistance

Early stages of the implementation of bicycle lanes in car-oriented cities often meet strong resistance caused by a variety of factors that will be discussed in this section. First, because in most cases the development of cycling infrastructure compromises space that would otherwise be allocated to car infrastructure and any action that restricts the use of private motor vehicles often receives resistance due to people's attachment to driving (Szell, Mimar, Ghoshal, & Sinatra, 2022).

Furthermore, shop owners are often concerned of losing customers if car accessibility would be curbed by the measures that limit car accessibility while case studies have shown revenues significantly increasing rather than decreasing (Bruntlett & Bruntlett, 2018).

Szell et al. found that developing bicycle infrastructure requires more investment and political strength at the start (Szell, Mimar, Ghoshal, & Sinatra, 2022). It is only when the network passes a certain threshold for the network to have gained enough critical mass to become sustainable and accepted.

By early 2020 the global Covid-19 pandemic hit and in waves mobility came to an almost standstill.

Subsequently, citizens saw their cities for the first time quiet and almost without cars the period. This als allowed authorities to more easily adjustment roads since they were barely used. After the first stress had disappeared many cities decided to take this opportunity to experiment with introducing bike lanes and other bicycle infrastructure. Cities like London in the United Kingdom have gained in bicycle infrastructure over that period (Moran, 2022).

Paris, by 2015 had already set plans to increase bicycle modal share and used the opportunities the pandemic offered for building bicycle infrastructure as will be discussed in the section on the case area of Paris

2.3 The How? Dominant discourses, a slow uncomfortable car or a faster healthy way of walking?

In the previous sections key technical considerations and pitfalls were discussed however an overarching goal of the policy was not yet discussed despite its relevance to both the methods and the outcomes. This section aims to provide an overview on critical theory on current discourse and provide directions of new discourses with regards to urban mobility and cycling. In developing nations especially, cycling is still seen as the lesser means of transport compared to private motorized vehicles and therefore this section is relevant to case an areas like Bangkok.

Discourse of mobility affecting the urban fabric

Infrastructure is designed on principles that are part of a discourse, a narrative or perspective that shapes the decision process and desired outcomes as is also indicated by the quote of Meadows (2008). In only a few cases the underlying discourse is addressed in literature on mobility, while this affects most decisions as the quote also highlights.

> *"The language of an organization is not an objective way for describing reality - it determines what its users see and which actions they undertake."*
>
> *(Meadows, 2008, p. 174)*

The famous phrase in cycling literature is "*build a city for cars and you get a lot of cars, build a city for people and you get a city suited to people*". Countries like the Netherlands and Denmark, despite having high modal shares of cycling, have infrastructure that still is largely designed on the principles of cars and pedestrians. Language and power relations are indicators of this, in the case of an accident often in the news is reported of a car hitting a cyclist rather than a car driver harming a cyclist. The context of accidents involving cyclists often report casualties while injury is most often caused by collision with motorised vehicles, in most cases cars. This car dominant bicycle accommodating system is also highlighted in the following quote:

> *"As Dutch planners have discovered over the years, the most important part of an effective walking and cycling plan is the car plan."*
>
> *(Bruntlett & Bruntlett, 2021, p. 9).*

Despite the overgeneralization, the core of the message can be seen in the way we think about cycling infrastructure. Often bicycle infrastructure guidelines present the best cycling infrastructure being separated bicycle lanes since they provide most safety. Yet in this case the safety is mostly a protection from car traffic.

While often bicycle networks are developed focusing on commuting therefore making the trip as efficient as possible, they often fall short of desires for cyclists. Car infrastructure is mostly following flow logic since early traffic engineers often were educated in flow dynamics of water, like sewage systems. Though, cycling infrastructure requires a more specific approach that takes more factors into account (Forsyth & Krizek, 2011).

Tragedy of the cars

Despite decades of scientific evidence on the negative impacts of cars especially in urban contexts, individual gains are perceived to outweigh the societal burden. The theory of the tragedy of the commons can explain part of this inconsistency, illustrating the scenario of shared resource where the costs of overuse are equally borne by society as a whole while the higher individual benefits are only for the user (Hardin, 1968; Ostrom, 2015).
The contribution of cars to common shared resources like air and noise pollution, the decrease in safety and the negative impacts of the car roads for communities, impact society as a whole yet are often not connected in the individual decision for car mobility. The majority of the indirect costs, financial and societal, of private motorised vehicles are paid by society as a whole and therefore called external costs. These findings can both be used as an explanation for car ownership as well as a reason for steering mobility away from private motorised traffic.

The travel constant of Marchetti, do speed gains result in less travel time or in gained travel distance?

In empirical research on travel data by Zahavi revealed a constant of travel time regardless of travel speeds. Marchetti connected this to a constant that would balance the drawbacks of travelling with the advantages (Marchetti, 1994). More specifically, travelling can be seen as an investment with a risk and a potential gain whereby the risk at some point exceeds the gain for people as Marchetti described.
The theory was strengthened by both travel data and the geographical spatial dispersal patterns that underpin the theory. People spend on average 13% of their income on travelling and an hour per day as an investment, regardless of their speed. Therefore, speed did not achieve the time savings it advocates. First comes the ability to travel further, then comes the need to travel further, dispersing our destinations further and further at higher speeds. As this dispersal pattern is the result of fast mobility it is also the cause of it since the greater distances that are the result of car mobility also require the car increasingly putting a society in a lock in situation. Therefore, commuting at slower speeds create greater proximity when applied in critical mass since travel time on average is not influenced by speed. Dominant discourses on mobility still portray travel time savings as the main aim of infrastructure and therefore portrays travel as a disutility.
With speed as the aim, and movement just a trip from origin to destination the environment of the trip becomes irrelevant. The way we think and perceive mobility and our addiction to speed is demonstrated in Figure 5, Figure 6 and Figure 7. Key to the theory of Marchetti are lessons for future developments of mobility and opening up the level of choice we have since gains in speed have not brought travel time cuts, therefore less speed will not make us gain travel time. We can make mobility safer, more meaningful while time allocated to mobility can stay at a constant.

Figure 5: Dynamism of a Dog on a Leash (1912) — Giacomo Balla, a painting of the 20th century depicting the addiction to speed

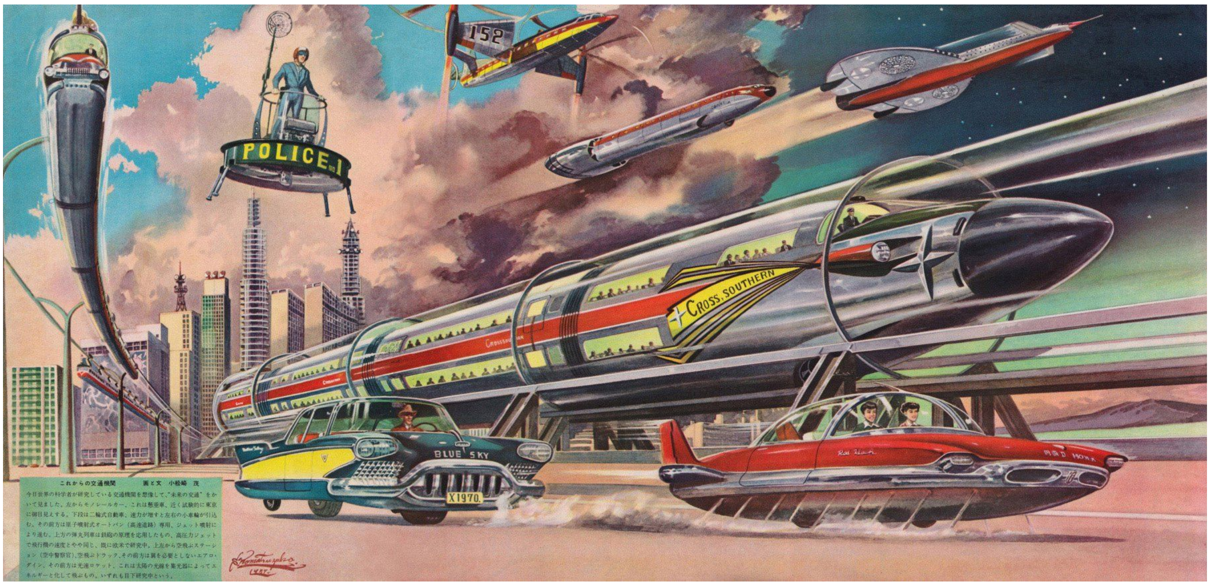

Figure 6: Futurist mobility scenario from the 20th century, connecting two spatially disjointed activities, where is the landscape (Brainoiz, w.d.)

Figure 7: Cycling superhighways, change of mode of transport though little change in discourse. Source (Shadbolt, 2015)

Relations of the build environment and mobility

Mobility and spatial developments are coevolving and influencing each other, in other words they are in a symbiotic relationship. Transit oriented developments have shown this in landscapes and many of the spatial distributions are linked to the dominant mobility type. In developments of mobility often the current situation and spatial organisation are presented as a given and mobility transitions are made on the basis of current dispersal patterns. Paris introduced the concept of the 15-minute city, a framework that aims for most amenities to be within a 15 minutes travel radius from residents.
Guiding the directions of development based on proximity of functions can help to restore the decline of facilities that was caused by the ability of the car to travel more easily. The framework aims to change the current urban layout in favour of more sustainable forms of mobility. Policy frequently uses incremental steps in order to change a situation however these might not be sufficient in the systemic change that is required. The fluidity of the urban fabric and built up area has allowed its current state to arise yet can equally create more desirable future states supporting more sustainable and desirable cities.

The allure of speed has fascinated humans for centuries, but it gained particular attention in the 20th century with futurists and has since become of great importance especially in relation to cars, as reflected in the following quote.

> *We declare that the splendour of the world has been enriched with a new form of beauty, the beauty of speed. A race-automobile adorned with great pipes like serpents with explosive breath... a race-automobile which seems to rush over exploding powder is more beautiful than the Victory of Samothrace.*
>
> *(Marinetti, 1909, p. 1)*

In mobility the example of the car is characteristic, since this evolved in the wealthier regions of the world from a means of transport for the well off to a standard of adult ownership creating a near necessity of car ownership. Since the society and landscape is made to function for car mobility, deviating becomes increasingly a necessity to function in society as Illich described as part of the Radical monopoly (Illich, 1978).

Any industrial product that comes in per capita quanta beyond a given intensity exercises a radical monopoly over the satisfaction of a need.

(Illich, 1978, p. 14)

In the 19th century Jevons discovered in the emerging industry that when gains were made in efficiency, rather than producing the same for less factories would actually produce more (Jevons, 1865). This can also be seen in mobility as the gains in reach causes people to travel more. The authors Illich, Marchetti and Jevons have therefore, each with a different perspective shown the mechanisms that have contributed to the current form of mobility and its limitation to sustain.

Discontent with current discourses of mobility is often mentioned regarding the discourse of novelties in mobility (Verkade & te Brömmelstroet, 2022). Consequently, in the development of new mobility systems understanding the discourse of the current system and its alternatives is of relevance in the development of future systems.

Network analysis and planning with geoinformation

The current increase of interest in the implementation of cycling infrastructure in urban contexts causes a demand for effective methods and tools (Rybarczyk & Wu, 2010; Cooper, 2017; Cabral, Kim, & Shirgaokar, 2019; Capodici, D'Orso, & Migliore, 2021). The current data availability and abilities to model using spatial data analysis software allows for promising geo data analysis tools (Wysling & Purves, 2022; Rybarczyk & Wu, 2010; Iacono, Krizek, & El-Geneidy, 2010; Capodici, D'Orso, & Migliore, 2021). While analysis using geodata on motorised traffic is well established, methods for non-motorised traffic are less established (Iacono, Krizek, & El-Geneidy, 2010; Wysling & Purves, 2022; Cooper, 2017). The methods for cycling and walking deviate in some aspects from motorised mobility due to differing requirements and characteristics.

Travel data on cycling is scarce and therefore understanding of the behaviour is also scarce. Multiple scholars have mentioned that this makes modelling of common routes and destinations difficult (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021; Iacono, Krizek, & El-Geneidy, 2010). A second reason is that non-motorised mobility has a smaller average trip reach and therefore the resolution of amenity data has to be higher. Subsequently, the shorter trip distances must be sufficiently accurate to do reliable analysis (Rybarczyk & Wu, 2010).

Thirdly, travel data frequently uses zonal codes however for cycling these are too large in scale to model (Rybarczyk & Wu, 2010).

Finally, data on trip density of an area are important, though are not always available. In many of the analyses this is assumed to be constant throughout the city, while this is far from accurate. Furthermore, some authors noted that modelling cycling comes with a complex multidimensional logic compared to motorised means of transport (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021; Iacono, Krizek, & El-Geneidy, 2010). As many of the techniques that are used in traditional motorised traffic analysis cannot describe the outcomes of cycling a different method was applied that tried to capture the behaviour in pattern language (te Brömmelstroet, Nello-Deakin, Quillien, & Bhattacharya, 2021). While the methods were successful the outcomes are hard to use in geo analysis, and thereby function as an indicator of the difficulty of modelling cycling behaviour.

Suitability and desirability, in the context of modelling

In bicycle network planning with geo data analysis two methods are common, a supply and a demand side of the analysis (Rybarczyk & Wu, 2010).
The *Supply* side analysis is focussed on evaluating the suitability for cycling of street segments. Often safety is a key determinant in this analysis whereby methods such as Bicycle Level Of Service (BLOS) or the Bicycle compatibility index are used for analyses (Rybarczyk & Wu, 2010). These methods are also frequently used in research on bicycle route planning as a step before the actual modelling of potential trips. While they provide approximations to the cyclability of road segments, on their own they are not supplying the information that is needed to provide useful data on where cycling networks lack cycling infrastructure since the likeliness of cycle infrastructure also relies on the demand for cycling infrastructure (Rybarczyk & Wu, 2010; Iacono, Krizek, & El-Geneidy, 2010). Next to that, as data availability and categories vary in different case areas and cultures the variables chosen to evaluate the segments varies (Capodici, D'Orso, & Migliore, 2021). Similarly, the traffic volumes and types differ per city therefore, despite the need for universal applicable methods, the methods need flexibility.
The *Demand* based analysis focuses on the demand of cycling trips with various methods often derived from the more developed analysis of car infrastructure (Rybarczyk & Wu, 2010). Often data on population density and popular destinations that are likely to be visited by bicycle is used. Popular destinations are related to education, shopping, healthcare and supermarkets (Capodici, D'Orso, & Migliore, 2021).
While these variables are to a large extent comparable in most cities, both the data as well as regional differences need to be taken in account. However, since it doesn't include things such as safety and attractiveness of cycling routes it is not sufficient on its own. Combining the two methods, supply and demand, has been seen as promising with regards to planning for cycling infrastructure since it takes both the suitability as well as the demand for routes in account (Rybarczyk & Wu, 2010).

With the contribution of analysis software, bicycle facility planning models have shown the potential to perform multicriteria analysis combining effectively the demand and supply side (Rybarczyk & Wu, 2010). This mix of methods is increasingly used in cycling infrastructure mapping, including in analysis of Wysling & Purves (2022) (Huber, 2003; Rybarczyk & Wu, 2010; Wysling & Purves, 2022; Cabral, Kim, & Shirgaokar, 2019; Capodici, D'Orso, & Migliore, 2021).
In the case of the analysis of Wysling & Purves (2022) the following steps are taken in line with the supply and demand framework. The bicycle suitability is focusing on the suitability of the street segments since it evaluates the street segments on their suitability for cyclists yet does not include in this step the demand for the road as a route. In a later step, the bikeability is calculated using popular destinations in the case area. It is recommended that the two sets of data are combined to do an analysis of the network (Rybarczyk & Wu, 2010). For a more detailed description of these methods the later methods section is recommended. Combining these

two methods, can reveal where the two mismatch and show bottlenecks as several authors have found (Cabral, Kim, & Shirgaokar, 2019; Wysling & Purves, 2022; Capodici, D'Orso, & Migliore, 2021).

Relevant theory and findings derived from other studies and literature discussed in this section

The bicycle is a sustainable option for mobility however some factors influence its capacity to be a viable alternative to non-sustainable alternatives. Compared to other means of transport the bicycle is most effective in high density areas with short average trip distances, and therefore most suitable to the urban context. Synergies of cycling with public transport can increase the use of both means of transport. Therefore, models can best connect both means for the synergies to be effective. Filtered permeability is an effective method to selectively impact the attractiveness of specific modes of transport and for cycling can stimulate both safety and directness. Current narratives on mobility have created unfavourable conditions like increased travel distances and dangerous traffic. The choices made on the topic of mobility must be considered carefully and with a critical perspective. Discourses on mobility do not only shape the mind, they also shape the society and mobility demands and therefore are an important component in cycling improvements. Shared mobility can be a valuable way of stimulating cycling yet comes with its limitations and in many cases dependencies on private companies.

Safety is key for cycling to increase, since it is the main determinant for people to cycle as cyclists are vulnerable road users. Predictions of trips often fall short in assessing the route choices of cyclists since data for cycling is underdeveloped however elevation and safety are strong variables. Increasing attention is drawn to the capabilities of using geo data and analysis as guidance for policy development on cycling infrastructure. Successful methods often include gradients and several variables determining safety for assessing the supply side of a cycling network. The demand side is often based on popular destinations however, since route data is scarce for cyclists there is a level of uncertainty in this part of the analysis.

The following diagram, shown in Figure 8, presents the conceptual model for this study. Step 1 is the desire for cities to change their mobility shares to accommodate cycling more. This is followed by step 2, an analysis of the discourse and subsequent guidelines for which the theory of this theoretical section forms the basis. Step 2 will be performed on both case areas, Paris and Bangkok. The third section, tests the applicability and potential contribution of the infrastructure network analysis tool developed by Wysling & Purves (2022) for the case area of Bangkok. Step 4 is the result following from step 2 and 3 providing policy recommendations for the desire formulated in the first step.

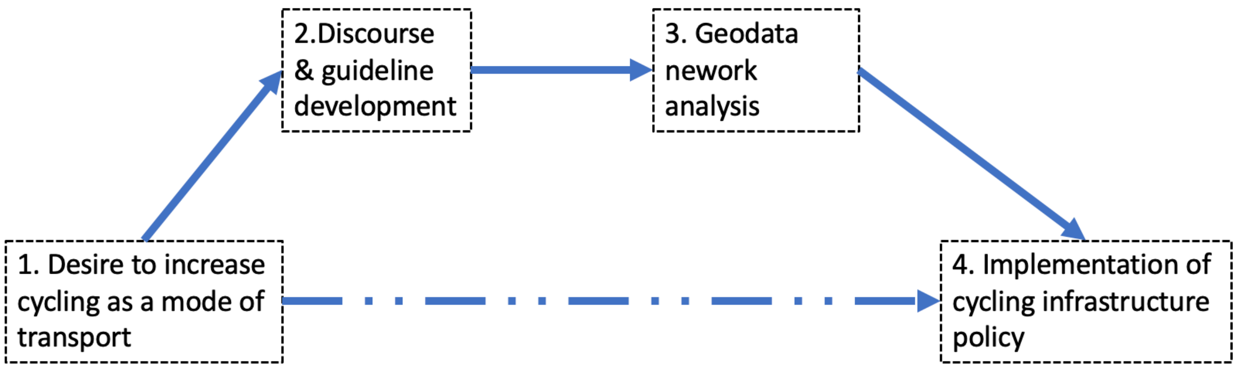

Figure 8: pathway of bicycle network development

3. Cycling in the South East Asian context

The model and most of the methods for cycling implementation discussed in the previous paragraph are developed in the European context. Therefore, this part of the study aims to describe and compare the cycling policy and levels of several cities in Southeast Asian nations. These findings can offer insights in cycling implementation and the applicability of European developed cycling theory in the cultural and geographical context of Southeast Asian cities. First, the high cycling rates and cycling orientation of Taiwan will be discussed.

Taiwan

Taiwan or the Republic of China is an island with high density cities and a thriving bicycle industry yet the bicycle mode share in cities is remarkably low with modal shares in 2003 at only 3% and 5,5% in 2014 (Mahadevia, 2008; CityLock, 2021). The bicycle ownership in the city of Taipei is only 0.25 per household, twelve times lower than the Netherlands. The bicycle infrastructure in the prefecture of Taipei is with 205 km in 2006 significant in size however the other 16 regions, that were studied by Mahadevia, each have around 30 km cycling infrastructure in their prefecture (Mahadevia, 2008). The main focus of policy and resulting cycling infrastructure is aimed at recreational use connecting cities and nature areas, and therefore less within cities (Mahadevia, 2008). While cycling in the 1960's was still common, the introduction of small motorcycles from Japan in 1968 and resulting high popularity have pushed transportation over to these light motorcycles that are still popular with currently over 12 million driving on the island and only 5.7 million cars at the same time (Mahadevia, 2008).

With congestion and pollution levels increasing the government has adopted plans to strive for more sustainable means of transport. Bicycle sharing, called YouBike, has become a popular means of transport that is often linked with public transport stations (Chen & Chancellor, 2020; Yen, Mulley, & Yeh, 2023). The bicycle industry has grown to the fourth biggest bicycle producer in the world with an annual production of 4.7 million bicycles. The potential for Taiwan to grow in bicycle mode share is large especially if it invests in its now underdeveloped commuter bicycle network (Mahadevia, 2008). As described, despite a large bicycle manufacturing market and favourable city densities, having bicycle infrastructure in cities is an important factor in bicycle ridership.

Peoples Republic of China

Rapid economic growth and strong urbanisation have put pressure on transport systems in cities in China. The rise and popularity of the private automobile has caused serious congestion and pollution issues. Public transport and cycling have been in decline in relative modal shares. The bicycle industry of China is among the largest in the world and despite declines in popularity is still relatively popular. The bicycle modal shares and cycling infrastructure availability differ greatly between cities in China with trip shares ranging from 1% in Chongqing to 56% in Shijiazhuang (Mahadevia, 2008). Low elevation more than climate was mentioned as an influence on cycling rates, in line with the findings of the theoretical perspective section. Two main trends in the context of China are the decrease of regular bicycles and the increase in E-bikes. The first, as a result of associating regular bicycles as a means of transport for the poor, as the poor countryside still uses regular bicycles. The e-bike use is a trend in avoiding congestion for low- and middle-income citizens and seniors. Some cities control and sometimes even restrict e-bikes, pressing growth of this specific category of bicycles. To summarise, ridership in mainland China varies and so does its level of bicycle infrastructure.

Vietnam

Vietnam has many similarities with the area of interest for this analysis, Bangkok, in terms of culture, infrastructure, and climate.

The southern region of Vietnam is on the same latitude as the middle of Thailand giving similar tropical climates. Both the regions have developing economies with next to car ownership also high levels of motorcycle ownership.

Two major cities in Vietnam, Hanoi and Ho Chi Minh city, have developed policy on how to include cycling infrastructure in recent years. First the policy in the capital and government seat is described and then the city of Ho Chi Minh is described.

Hanoi

The northern city of Hanoi houses the government of Vietnam and has over 8 million inhabitants in the metropolitan area of the city. In new policy documents, called “2022-2025 traffic congestion plan”, its government proposes among the measures to reduce the congestion, bicycle specific lanes (Son & Va, 2022). According to the policy documents, cycling is valuable for the future as a means of transport since it is a modern, civilised trend and implemented by many countries. This explanation is remarkable as the country for decades heavily relied on bicycles as a means of transport (Nguyen, 2022). Especially Hanoi was by the 1990’s capital of non-motorised vehicles as 70% of the trips were made cycling or walking. This is almost double the share of the city of Groningen, which now is among the highest in bicycle trip share worldwide (Nguyen, 2022). The policy documents also mention the advantages in terms of the environment, health and suitability to combine with public transport.

A pilot was established however the effectiveness of the small-scale implementation of bicycle lanes resulted in low ridership and criticism as it compromised car infrastructure. These findings align with the theory described before on the introduction of cycling infrastructure and the threshold that is required for success. The importance of developing methods for large-scale network implementation, wherein this study aims to contribute, is indicated by this case.

Ho Chi Minh city

The southern Vietnamese city of Ho Chi Minh is in size and population number even bigger than Bangkok. The inner city has a bike sharing program that aims to increase bike shares (Phuong, 2020). Often docking stations are placed near the public transport stations in line with the ideas of creating synergies in public transport and bicycles. However, as the cycling infrastructure network was not addressed the ride shares of the bike sharing only had moderate success. The cycling levels currently are low and specific infrastructure is lacking while the city, like Hanoi, had high cycling shares in the 1990’s.

4. Paris and Bangkok, cycling related development and their potential

This section aims to describe and compare the case area used by the model of Wysling & Purves (2022), Paris with the case area of this study Bangkok. The analysis will use the concepts of the theoretical framework and compare the two areas based on general characteristics, relevant policy and current bicycle friendliness.

4.1.1 The case area of Paris

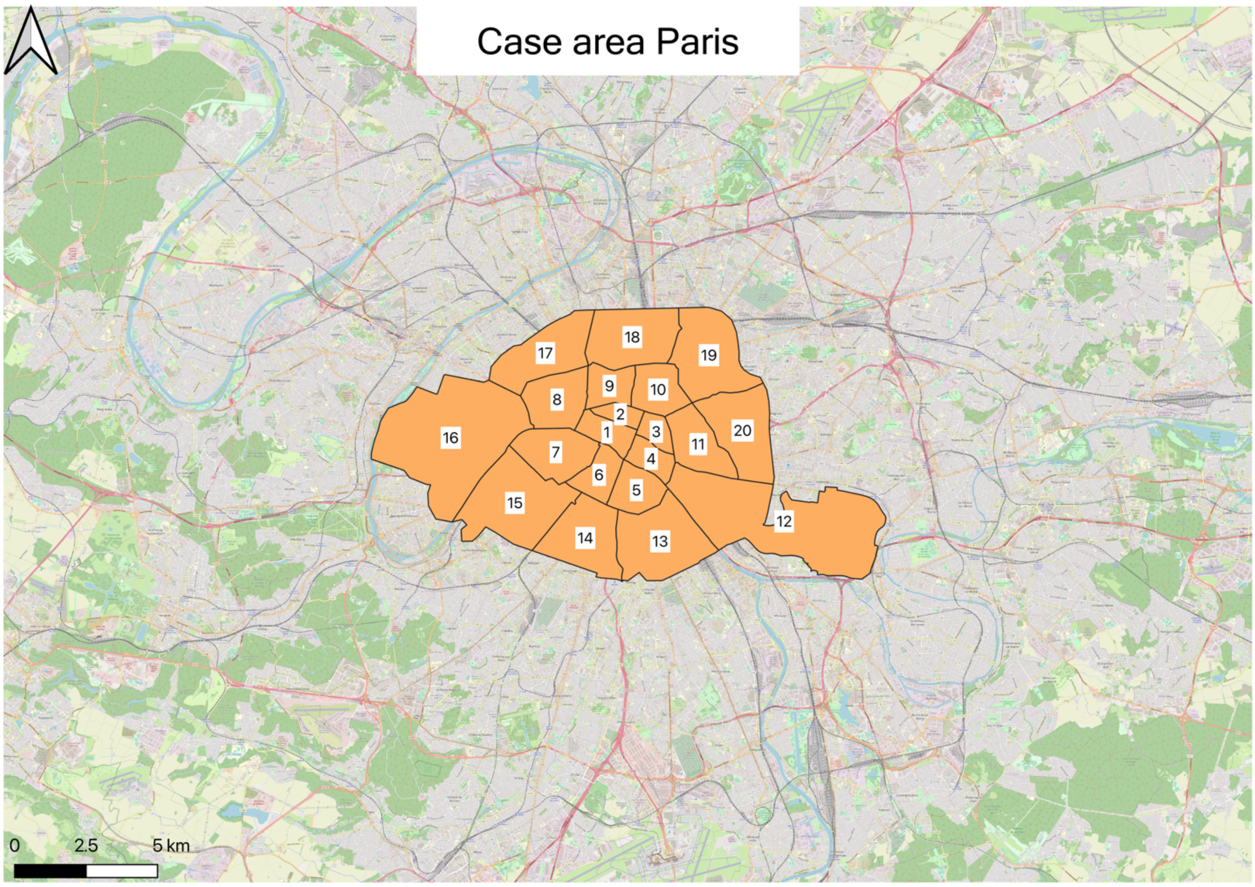

Figure 9: Map of the districts (Arrondissements) of Paris, OSM base map, data of Wysling & Purves (2022)

The city of Paris, capital of France, is a city with over 11 million people living in the metropolitan region. The city has a central district, indicated in orange in Figure 9, with its own municipal authority and houses 2.2 million people. The area of this core district is 105 km² and therefore has a population density of around 20.000 /km².

4.1.2 Baseline assessment, Paris wasn't always cyclist friendly

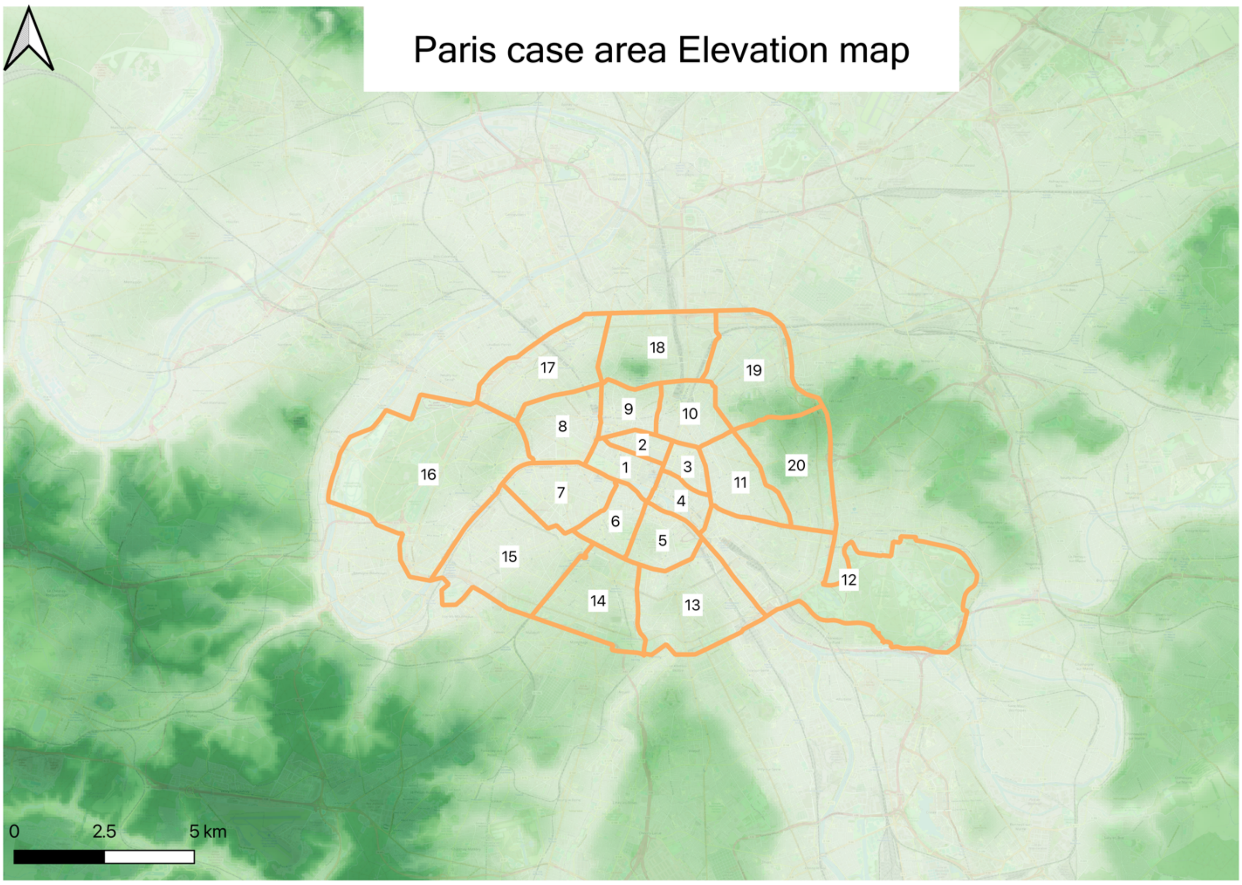

Figure 10: Elevation map Paris

The analysis of Paris adds to the relevance of Wysling & Purves (2022) to include elevation in the formula of the bicycle suitability since the city has elevation that can impact cycling. The extent of elevation is limited however as can be seen in Figure 10 with the height indicated from low in light green to high in darker green.

The public transport in the case area is provided by a subway system that on average serves 5.23 million passengers per day, a tram and ample bus lines.

The following section will describe the state of the case area of Paris prior to the extensive bicycle policy of 2015 on for this study relevant variables. By 2000, the inner city had a bicycle mode share of 1% of the trips. In 2010 the bicycle share had grown to 2.5% indicating growth in the use of the bicycle as a means of transport yet also showing the share still was relatively low compared to averages in Denmark and the Netherlands (Pucher, deLanversin, Suzuki, & Whitelegg, 2012). However, the bicycle trip shares of Paris still far exceeded the countrywide averages (Najdovski, w. d.). By 2010 the city of Paris had car ownership rates of 50%. Part of this could be explained, comparable to other cities, by extensive use of public transport yet also facilitating the car in the city. Pucher at al. found that seniors and women were underrepresented in the group of cyclists of Paris, something that often coincides with unsafe cycling conditions (Pucher, Dill, & Handy, Infrastructure, programs, and policies to increase bicycling: An international review, 2010). The effect of safety in numbers was small with its low ridership. The city of Paris increased its cycling network from 151 km to 439 km between the years of 1999 and 2008, and therefore reported a growth of the network of 10%. However, most of the cycling infrastructure in Paris was of low-quality, mostly allowing cyclist to use the bus lanes. To conclude, despite efforts made to increase cycling rates in Paris between 1999 and 2008, the methods were insufficient to elevate the cycling levels that were seen as a result of the later, more extensive Plan Vélo policy.

Table 1: Modal share based on trips of both metropolitan Paris and the inner city before Plan Vélo implementation, source: (Najdovski, w. d.)

Mode	***Paris metropolitan region***	***Paris***
Walk	38,7%	60,5%
Bikes	1,6%	3% -5%
2 motorised wheels	1,4%	1,8%
Public transport	20,1%	27,3%
Cars	37,8%	6,7%

4.1.3 Paris policy, rightfully receiving international fame

A relevant change to the cycling share came in 2015 when a new board was voted into power for the central municipality of Paris that introduced ambitious cycling plans (Najdovski, w. d.). During the first term of the major Anne Hidalgo ambitions plans were presented in cycling stimulation as part of the larger plan of the 15-minute city.

This policy aimed at bringing destinations in closer proximity to each other, reducing the average trip length to increase the number of trips that are within a cycling distance of 4km (Wysling & Purves, 2022).

The Plan Vélo aimed at achieving a 15 % mode share for bicycles, with an initial mode share of only 2.5% in 2010 a substantial increase was set (Fenu, 2021; Pucher, deLanversin, Suzuki, & Whitelegg, 2012).

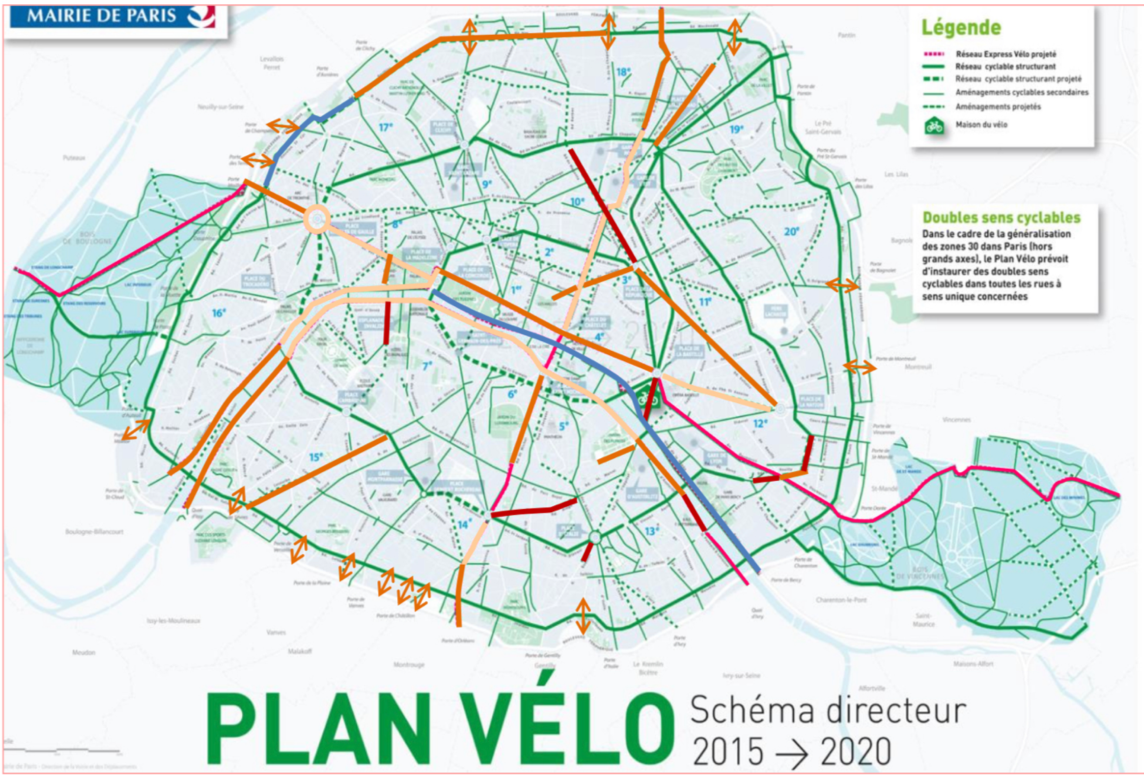

Figure 11: Map of cycling infrastructure plans as part of the Plan Vélo 2015-2020, Paris source: (Najdovski, w. d.)

The cycling related developments, as described in literature and maps, are concentrated in the core of the city of Paris in the central district. Connections to the region and municipalities surrounding this area, the Banlieue, have been established though their involvement in the extensive bicycle infrastructure development is limited as also shown in Figure 11. with the arrows as these connections. Subsequently, their bicycle trip shares and accommodating infrastructure are low as can be seen in Table 1.

The cycling enhancing policy was introduced with a wide array of measures, more than infrastructure alone. These measures were based on the desired growth of the cycling share to 15% of the trips by 2020, which it reached (Municipality of Paris, 2021). In terms of budget, a formerly unseen budget of 150 million was allocated to the program. This is for a wealthy city such as Paris feasible while in developing countries this might not be feasible. This budget aimed to double the total length of cycling lanes from 700km to 1.400km (Najdovski, w. d.). The allocations of cycling infrastructure followed the logic of effective development based on the network as a whole. Continuity, as also described in the CROW manual of cycling infrastructure, is one of the guiding principles for cycling network development. This is also applied in the development of the cycling infrastructure of Plan Vélo as indicated by the increase in connectivity shown in Figure 12 (CROW, 2017; Najdovski, w. d.). This was also included in the methods of the model of Wysling & Purves (2022).

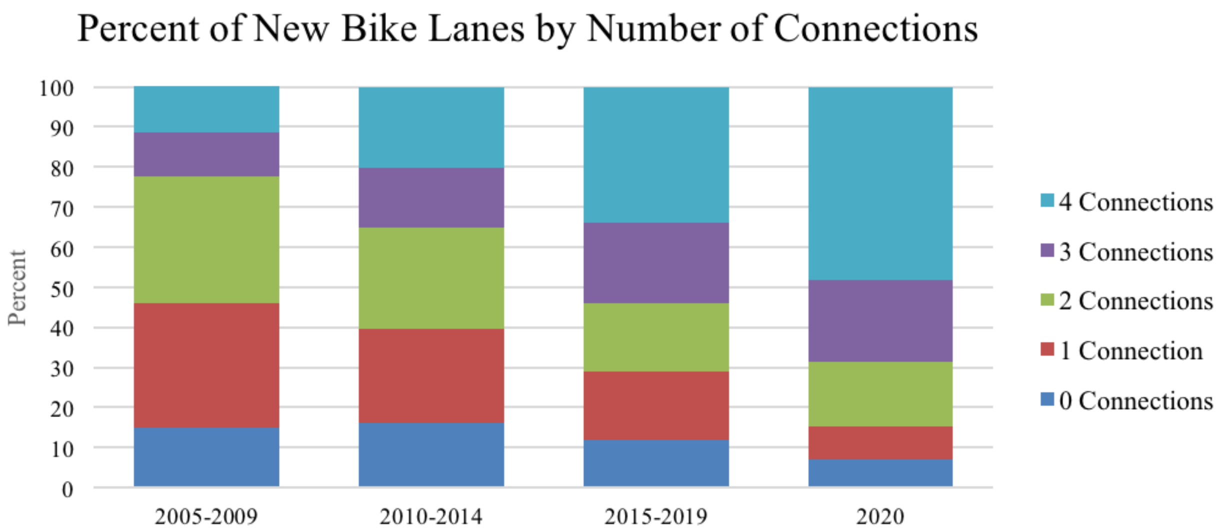

Figure 12: Connectivity of cycling infrastructure segments between 2005 and 2020. Source: (Moran, 2022)

Next to this, the plans have various measures to increase social acceptance of cycling and promote its status. The plan also encompasses the construction of sufficient parking spaces and extending the bike sharing system. Furthermore, the developments also focus on intermodal commutes, strengthening both cycling and public transport as described in the theoretical section, in the allocation of cycling related infrastructure. Finally, the network aims to contribute to bike touring, long distance travel routes, to make travelling for leisure on long distance by bicycle more attractive. The policy, as described, encapsulates the change in favour of sustainable mobility holistically in line with many of the concepts of the theoretical framework and often praised in literature (Wysling & Purves, 2022).

The 15-minute city as a concept can give guidance and create the spatial layout of destination origin favouring the bicycle as described in the theoretical perspective section. This is an example of a proactive planning practice that has great potential.

This framework can provide valuable direction for the development of cycling infrastructure avoiding the use of incremental steps without direction.

4.1.4 Current network, on the right path

Observations: Paris in a transition to a higher cycling share

Remarkable change of Paris from an almost completely car dominated city towards more bicycle usage and increasing car free zones. Residents are mostly enthusiastic towards this change. The efforts made are clearly visible in some areas with large bicycle lanes and parking facilities in places that used to be car parking spots. Social techniques to promote cycling, like the bicycle counter on several paths were built as can be seen in Figure 19 in the Apendix. The car dominance also still. Shows as most streets allocate most of their space to cars. Next to this the severe gridlock that still occurs in rush-hour shows the urgency and market for a sustainable and more suitable mobility alternative. Noteworthy is that the on road public transport, the buses and trams, frequently get stuck in rush hour traffic because of lacking separated road space for public transport. This causes more people to take the car as public transport does not provide a benefit over the car (Russo, Adler, & van Ommeren, 2022)

While international coverage of the bicycle infrastructure of Paris focuses on the streets that have been transformed to cater for bicycle infrastructure, the map and my observations highlight that the city still has a lot to improve. Most of the parked bicycles were attached to fences on the pavement showing there is not enough dedicated bicycle parking. This was causing a conflict of space on the pavement frequently as seen in Figure 20. Parking for bicycles is often not given priority and therefore a frequently occurring problem for cities increasing their cyclability. Occasionally, bicycles were also stripped or molested indicating the streets are not always safe enough to park your bicycle. This can severely limit the likelihood of people owning a bicycle and forcing them, if they want to cycle, to rideshare bicycles.

The docking stations for the rental bicycles were clearly visible and the bicycles enjoy high ridership showing the success and need of this intervention as can be seen in Figure 21.

While mapping cycling infrastructure is quickly progressing, the translation of theory into practice still shows some weaknesses as shown in Figure 23. Converting the car infrastructure to also accommodate bicycle lanes requires courage, learning and dedication which shows for example in the street shown in Figure 22. Some streets have excellent bicycle infrastructure though because the network is still in an early stage, with rush hour cyclists must use the pavement to be able to safely travel through the city as can be seen in Figure 24 & Figure 25. The city at rush hour comes at an almost complete standstill while cyclists still manoeuvre through the traffic.

The new bicycle infrastructure

Attempts of shoehorning bicycle infrastructure in current, car-oriented infrastructure shows its constraints resulting frequently in confusing infrastructure decisions. Nevertheless, the fast and clever implementation of increasing overall connectivity of the network and combining it with the supporting components is noteworthy. Clearly indicating the cycling infrastructure, like in Paris through painted bicycles or specific colours, is of importance to the visibility for the policy for traffic as well as for promotion. The infrastructure, especially at intersections, that have proven to be the most dangerous for bicycles, were mostly following car logic and therefore unsafe for cyclists.

Summarising Paris, the city of romance and bicycles?

The case area of Paris has first been described in its span, population size and density. The population density was especially high with 20.000 residents per km^2. While most of the area is relatively flat, some clear hills and therefore considerable elevation differences were found. The public transport system was reasonably well developed and therefore suitable for multimodal trips supporting both the capabilities of public transport as well as the bicycle.

Before the extensive stimulation of cycling in the city the traffic was hostile for cycling and the cycling share was less than one percent of the total trips. Traffic, as Illich described, was dominated by transport leaving active means of transport out of the options for most residents (Illich, 1978).

The inner city of Paris, as described, has been increasingly successful in implementing cycling infrastructure despite its formerly car dominated streets. The inner city however, despite its ambitious plans, clearly still is in the process of development with regards to cycling stimulation and therefore does not yet match cycling numbers perceived in urban areas in Denmark and the Netherlands. While the network still is in development, especially extending to the wider surrounding metropolitan area, it is a promising start. The wide scope in policy as described, are strong points that provide valuable lessons on how to apply the cycling infrastructure in an effective way and therefore is often used as an example on how to plan for cycling in general.

In line with the theory described in the theoretical perspectives section the Plan Vélo is extensive in its implementation strategy focussing on the wide array of perspectives and elements involved in cycling stimulation.

The framework of the 15-minute city together with the extensive package of measures allow for a successful implementation and therefore a positive loop. This though, must be noted, can only occur with sufficient political will and financial capabilities.

The Plan Vélo is successful and can be regarded as an example for many cities around the world with similar aspirations.

4.2.1 Case area of this study, Bangkok

While sustainable mobility increasingly is prioritised in higher income countries such as France, developing nations still lag behind (Mohapatra, 2023). These countries with developing economies experience increases in automobile ownership rates without corresponding expansion in road capacity to meet the growing demand (Panthasen, Lambregts, & Leopairojana, 2020).

In cities in these nations traffic often comes to gridlock at peak hours, including the road based public transport. Bangkok, the second case area of this study, is no exception in this and is notorious for traffic congestion (Sintusingha, 2006; Panthasen, Lambregts, & Leopairojana, 2020).

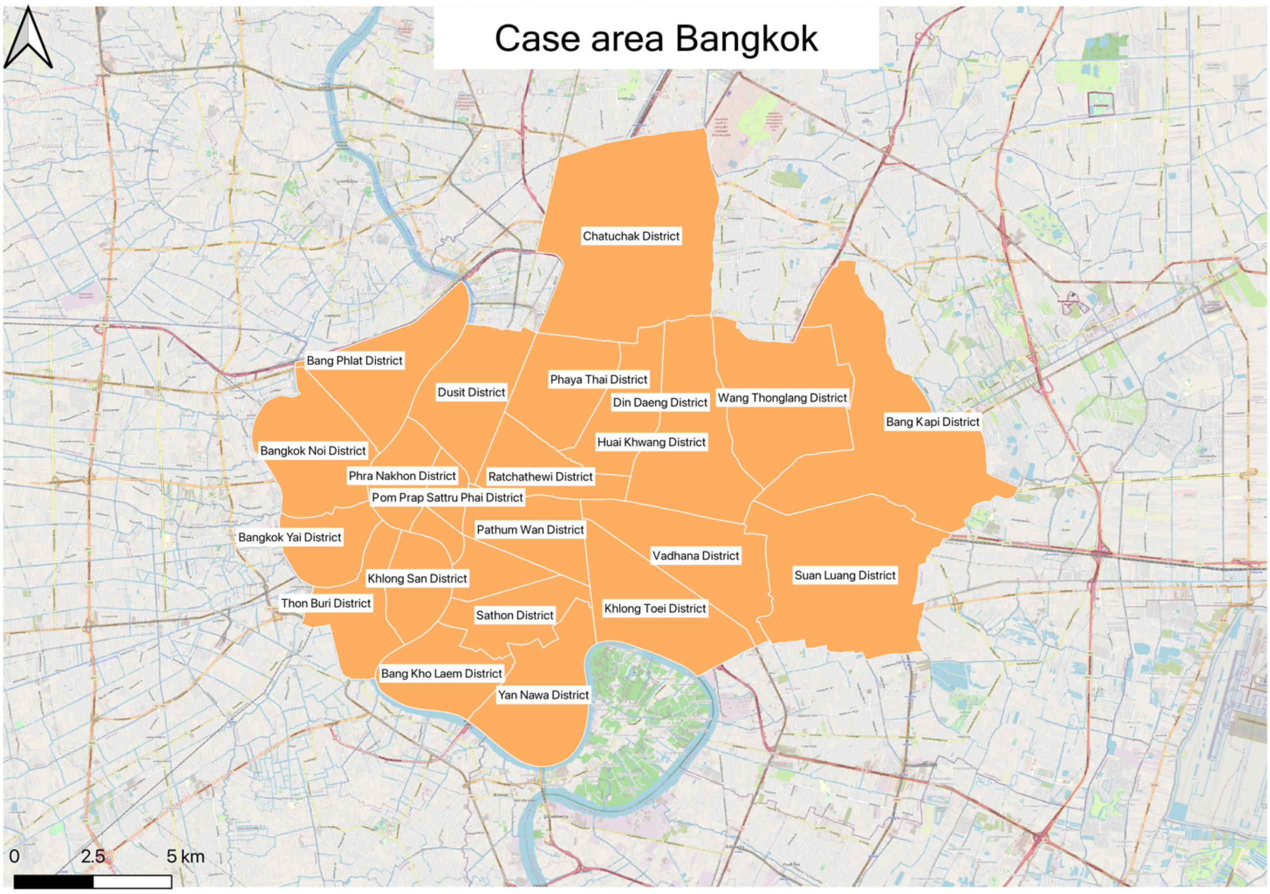

Figure 13: Bangkok, the central districts in yellow are selected for the case study source : (Open Street Maps (OSM), 2022)

Bangkok, centrally located in Thailand along the Chao Phraya River, differs in some aspects in its urban layout from Paris yet also shows similarities as will be discussed in this section.

Unlike Paris, the city of Bangkok does not have a clearly defined inner district due to the city's differing development pattern and late active planning.

Consequently, districts located in the centre of Bangkok were chosen to add up to a comparable population size to the inner city of Paris, which has 2.2 million inhabitants. An overview of the districts can be seen in Figure 13 and with population data in Table 4 in the appendix. The resulting case area is almost three times bigger with 275 km², therefore the density is clearly lower with 7300 people per km² compared to 20.000 per km² for Paris.

The decision to prioritise population size over area size was made in the selection process since the model was in no way constrained by area size yet is influenced by population size.
Furthermore, the amenities used in the model rely more on population size than on area size therefore making the population the key selective criteria for this study.
The districts that were selected are all governed by one authority, the BMA, therefore cohesive planning for all districts is feasible. As described by Bertolini the inner city, due to its high trip density and short average trip length, is most effective for bicycle stimulation (Bertolini & le Clercq, 2003). Therefore, comparable to the case area of Paris, the inner city was chosen for this analysis.

4.2.2 Starting point for Bangkok

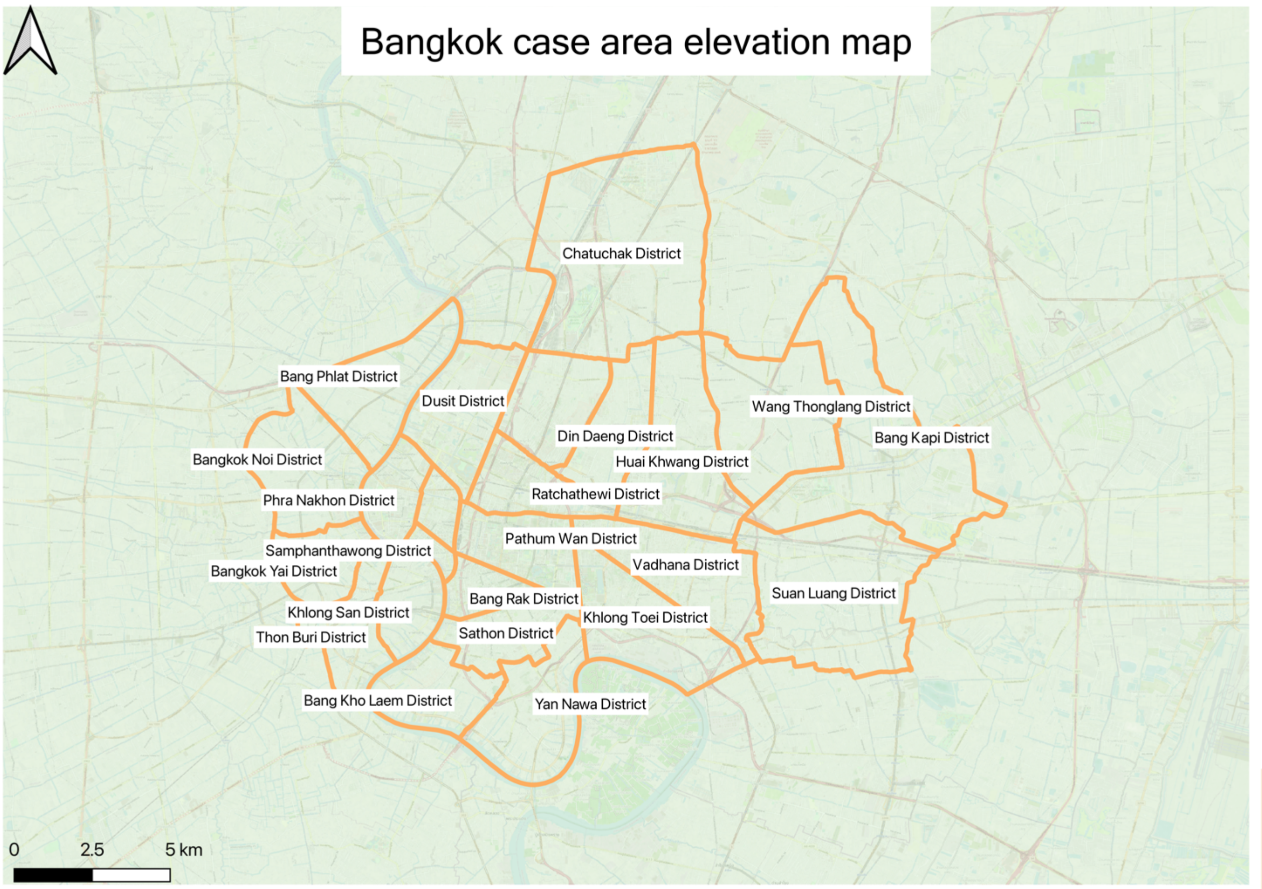

Figure 14: Elevation map Bangkok

The case area in Bangkok, despite being larger in size than the Paris case area, has less elevation. The map, Figure 14, also indicates the area as being almost flat. In theory this would favour cycling developments in Bangkok over Paris. The city has developed public transport in the form of trains, buses, subway systems and an elevated train. The buses, since there are no dedicated bus lanes, often get stuck in the traffic jams and therefore, comparable to Paris, do not meet their potential. Furthermore, Bangkok is notorious for traffic congestion often scoring as in the top five of most congested cities in the world (Sintusingha, 2006; Panthasen, Lambregts, & Leopairojana, 2020; TomTom, 2019). This is recognised by the government that over the years has committed to investing in Mass Rapid Transit (MRT) systems and attempted to increase cycling rates. The changes however must compete with the results of car friendly governmental policies, little filtered permeability by mode of transport and decades of sustained economic growth allowing increases in car ownership. On top of that the slow development of mass transit resulting in Bangkok being among the most congested cities in the world (TomTom, 2019; Wu & Pojani, 2016; Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022). Furthermore, if the city fails to decrease its unsustainable and increase its resilience through more sustainable means of transport, the conditions are likely to worsen since the tropical climate will intensify, leading to increased heat, flooding, and higher levels of air pollution, thereby increasingly hindering the transition towards active mobility. The current urban development steered by private motorised vehicles further amplifies the problem as urban fabric and mobility are strongly intertwined as will be discussed in the following section.

Superblocks in Bangkok, not super and blocking active means of transport

Bangkok has developed through lead frog development from the 1950's in a mostly organic, unorganised way resulting in increasingly big superblock structures near its edges (Sintusingha, 2006). These superblocks are permeable through partly accessible small streets, Soi's, and mostly surrounded by wide arterial roads. Due to this type of expansion of the roads and build up area the urban fabric develops in a grid like structure.
The resulting pattern of development and infrastructure are intertwined, as indicated in the theoretical perspective section. Subsequent development has led to the growing dominance of car-oriented infrastructure (Sintusingha, 2006). As Sintusingha described, the further to the edges of the metropolitan area of Bangkok, the larger the blocks become. And as the blocks become bigger the shortest route distance increases and options decrease because the larger the blocks the larger detours and therefore favouring the motorised means of transport over human powered transport as also indicated in Figure 15 (Sintusingha, 2006). Therefore, the radial expansion in increasingly large superblocks of the metropolitan area of Bangkok makes cycling harder to plan for as distance to the centre increases. Consequently, this is one of the reasons, next to population density and similarity to the case area of Wysling & Purves (2022), for the focus on the core of the city for the implementation of cycling infrastructure. As Bertolini described, the most feasible place for cycling is in areas with high trip densities and relative short trips (Bertolini & le Clercq, 2003).

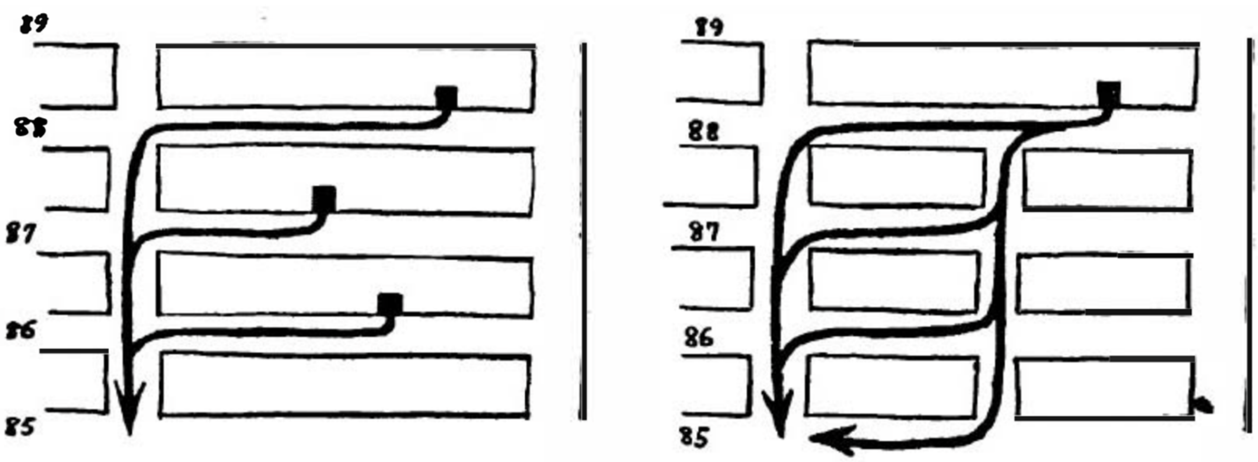

Figure 15: Effect of the size of the block on the directness and variety of routes. Source: (Jacobs, 1961, p. 179 & 181)

Residents motivations for cycling in Bangkok

For residents of Bangkok, as a case study points out, two categories of factors that influence the use of bicycles can be identified; travel behaviour and cycling policy (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). The factor travel behaviour included the travel time, travel cost and distance whereby the increase in these factors decreased the use of bicycles. Another factor influencing travel behaviour proved to be the availability of showers at work. The second set of factors that are more relevant to the planning of cycling infrastructure were setting up cycling plans for each district and providing a bicycle exclusive network around Bangkok. (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). The choice to cycle, according to a survey, depends on factors that make cycling the most attractive option for residents in line with the theoretical section (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). Some of the policy recommendations go beyond the scope of this research, like the showers facilities at work, though the desire for a bicycle exclusive network through Bangkok does show the need for an extensive network (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). Research on the bicycle sharing system showed also that cycling still is for a marginal high-income group despite policy to make cycling widely accessible (Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022).

4.2.3 Policy of cycling stimulation of Bangkok, small steps are insufficient

Figure 16: Rattanakosin bicycle infrastructure map, source (Online, 2014)

The governing institutions of Bangkok recognise the bicycle as a beneficial means of transport for the city. Numerous attempts have been made to improve bicycle rates, though none have yet been successful (Panthasen, Lambregts, & Leopairojana, 2020). The main authority involved is the Bangkok Metropolitan Administration (BMA). For several years the promotion of cycling of the BMA has resulted in the earlier described bike lanes, bike sharing and public campaigns encouraging people to take up cycling. This yielded only partly success in Bangkok. This success focusses on recreational cycling while utilitarian cycling has not shown progress.

The role of stakeholder participation and its implementation has been found to be important in the context of Bangkok (Ratanaburi, Alade, & Saçli, 2021). The Rattanakosin bicycle route in the old and most touristic part of Bangkok shown in Figure 16 was developed in 2008 as part of the Bangkok Smile bike project to promote bicycle tourism (Ratanaburi, Alade, & Saçli, 2021). The development of the path went through several phases with differing institutions and departments taking responsibility. Early-stage stakeholder participation was found insufficient due to late involvement of stakeholders. Especially, the main stakeholder, the We Love Bangkok, We Love Bicycle Committee, had insufficient impact on the project (Ratanaburi, Alade, & Saçli, 2021). The short section of bicycle lanes was provided yet supporting measures to enhance cycling, in line with the array of measures of the theoretical perspectives section, were not implemented. Both the incomplete bicycle infrastructure as well as the lacking stakeholder participation gave the residents of the area dissatisfaction with the bicycle route. Therefore, the lanes had low public support and due to low ridership was perceived as a burden rather than a benefit. Furthermore, the branding and regulations were not in place at the introduction of the cycling paths leading to people parking their cars on the bicycle lanes causing the lanes to be blocked and eventually being neglected (Ratanaburi, Alade, & Saçli, 2021). Later stages of the project showed improvements in the process causing more acceptance of the residents. However, between 2016 and 2019 the political climate changed, and an event caused the initial temporal closure of the bicycle lanes (Ratanaburi, Alade, & Saçli, 2021). The bicycle route did not get enough political support for the re-opening of the bicycle lane. According to Ratanaburi especially the initial stakeholder participation or the lack thereof was the main cause of the failing of the implementation of the cycling route (Ratanaburi, Alade, & Saçli, 2021). The findings strengthen the importance of stakeholder participation to create public acceptance for Bangkok in particular and for the process of introducing cycling infrastructure in general.

As described earlier, the implementation of cycling infrastructure from scratch is most fragile when it has not reached the threshold proving its purpose, requiring tactful implementation. In other words, careful implementation is required for early acceptance of the cycling infrastructure, and stakeholder participation is an important aspect of this careful implementation.

4.2.4 Current network of cycling infrastructure

Bangkok has a low modal share of cycling, and the share is decreasing despite governmental investments (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). In a survey of 2018, the number of trips made in the Bangkok metropolitan region were 32 million per day. Of those, 70% were made by private vehicles, leading to severe congestion that adds to the urgency of Bangkok to change urban mobility (Panthasen, Lambregts, & Leopairojana, 2020; Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022). Currently, average speeds are only 10.7 km/h and 14.2 km/h in the peak morning and evening periods and therefore comparable to the speed of cyclists.

The public space is mostly paved to allow for maximum capacity for its traffic demands leaving little greenspace with only 1.8 m^2 per resident. Consequently, the permeable surface is low and therefore often contributing to the severity of floods.

Public transport in the Bangkok metropolitan area accommodates about five million trips by rail and four million by bus per day on average. The BMA has constructed bike paths with the aim of encouraging the use of the bicycle as a means of transport and therefore reducing congestion (Raha, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2015). However, the bicycle infrastructure is, when not in parks, often shared with motorists increasing the risks of accidents especially at intersections (Siridhara, w.d.; Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). Bangkok was not able to prevent the decline in cycling in the metropolitan area despite improvements to the infrastructure in 2008 with the construction of 23 new cycling and walking paths.

A survey revealed that the primary reasons for cycling for participants were going to nearby markets, and using it for recreational rides. The later, also is reflected in the type and location of current cycling infrastructure in Bangkok (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013).

Recreational cycling is despite its benefits to physical and mental health not significantly reducing the use of motorised vehicles as it does not compete with its purpose. Compared to Taiwan the recreational cycling infrastructure is not connecting cities through rural areas, though there are clusters of recreational cycling infrastructure mainly in parks. Despite the interconnectedness of the sections on the map below Figure 17, in 2022 the network was described as unsuitable for communing and even for recreational purpose inadequate (Sintusingha, 2006; Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013). Part of the bicycle infrastructure developed by the BMA was through ensuring enough space on pavements in pedestrian areas for bicycles (Raha, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2015).
The three main points of critique on the established bicycle infrastructure are that it is incomplete, it is not connecting housing with major economic activity centres and facilities such as bike racks, lockers and lights are insufficient (Sangveraphunsiri, Fukushige, Jongwiriyanurak, Tanaksaranond, & Jarumaneeroj, Analysis of the Characteristics of Bike-Sharing Program in Bangkok., 2022). Intermodal transfer facilities, the linking of multiple modes of transport by a hub as described in the theoretical section, are only in a few cases established (Ueasangkomsate, 2014).
Furthermore the current public transport system also shows its weaknesses. The weaknesses are for instance that the current bus lines in some cases have not been updated for as long as 30 years resulting in undesirable competition between later developed metro and sky train lines.

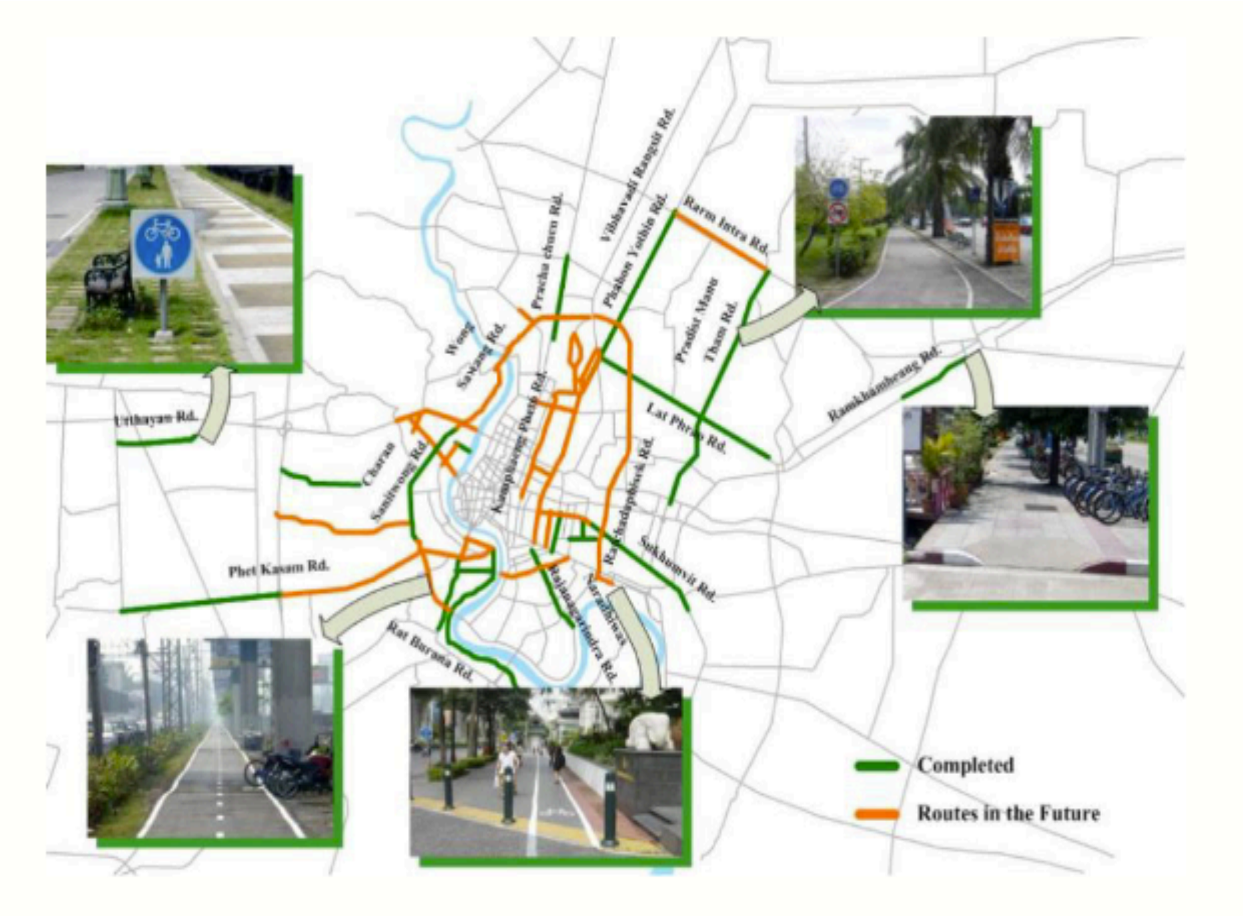

Figure 17 : Bicycle network in Bangkok as of 2012, source (Raha & Taweesin, Encouraging the use of non-motorized in Bangkok, 2013)

The Velib' like rideshare option for Bangkok is called PUN PUN, which was developed and owned by the local authorities to stimulate cycling with a focus on the dense inner city for its docks. While this system has expanded to 50 docking stations the ridership still is low. The docking stations are near high density development and public transit stops accommodating for first and last mile trips in line with best practices. While this system has the potential for stimulation of cycling, it is constrained by its environment. The cycling infrastructure, in surveys, was often the main argument for people not to use the facility. Subsequently, the development of cycling infrastructure in Bangkok can unlock the potential of the PUN PUN bicycles.

4.3 Comparability of the inner city of Paris and the inner city of Bangkok, the results of the case area comparison

This chapter has described the two case areas on factors relevant to this study and found the areas to a large extent comparable in variables that could not be affected by policy as also shown in Table 2. The case area of Bangkok, selected by population size and centrality in the metropolitan area, has a lower population density and bigger surface area. Both Paris and Bangkok have a metro network and bus system yet Paris also has trams while Bangkok has elevated trains. The elevation in Paris was more prevalent, therefore the case area of Bangkok, with regards to elevation, is more favourable for cycling. In this section the state of urban mobility in Paris before the cycling policy came into effect was described and showed resemblances to the current state of urban mobility in the case area of Bangkok.

The policy of Paris as part of the Plan Vélo does, next to extensive network-oriented development of cycling infrastructure, approach mobility in a wider perspective including discourses, public transport synergies and education campaigns. The policy for enhancing cycling rates was found to meet most of the criteria described as successful in the literature study and effective in enhancing the cycling share. Subsequently, the methods can be regarded as exemplary for the case area of Bangkok.

The cycling policy in Bangkok however was found to be narrow focussed and relying on small incremental steps that worked counterproductive and therefore insufficient in preventing the cycling rates from decreasing. The findings of this section have shown that based on relevant demographic and geographic factors were Bangkok and Paris are comparable. Consequently, it is reasonable to expect results similar to the case area of Paris in the case area in Bangkok if similar methods and tools will be used, among which the tool that is studied in particular for this study of Wysling and Purves (2022).

Table 2: Comparison of Paris and Bangkok case areas summarised

	Paris	**Bangkok**
Size	105 km²	275 km²
Population density	20.000	7300
Elevation	Some, but mostly flat	Flat
Public transport	Developed but very extensive	Developed but not very extensive
Current cycling share	15%	0%
Cycling policy	Extensive including: - Paths - Storage - Education - Campaigns - Subsidy for purchase - Street furniture for cyclist	Small - Aims - Barely any facilitation
Current state cycling layout	- Mediocre but developing fast	- Only some recreational in parks, no connectivity

5. Methodology based on the model of Wysling & Purves (2022) and Purves (2022)

The previous section indicated a great of level of comparability of the case areas of Paris and Bangkok on relevant variables and highlighted the effect of policy and models in steering the developments and policy. The starting phase, as discussed in the theoretical section, was found difficult yet decisive. In this phase casualties increase, conflicts with motorists intensify and stakeholders often oppose, while cycling numbers remain relatively low. This is where the model of Wysling & Purves (2022), as part of a recent growth in methods for the development of cycling networks, comes in. In assessing the supply and demand side of cycling infrastructure networks, it provides information on weaknesses of the infrastructure network. The model is a tool to guide policy by providing data on these strengths and weaknesses, leading to potential improvements of the network of cycling paths. As described before, the network of cycling paths and therefore this model is only a part of a wide array of measures to improve cycling rates. As the analysis does not work with sensitive data, ethical considerations were irrelevant to this method. This section aims to describe the methods used for this study by first describing the general methods that were followed from the study of Wysling & Purves (2022). After that, modifications as a result of the different data availability for the Bangkok case area will be discussed.

Case area

The study by Wysling & Purves (2022) used as its case area the inner city of Paris, delineated by the ring road as can be seen in Figure 9. Furthermore, as discussed before the area is where most cycling development happened and all its districts are governed by one authority.

The facilitation of cycling mostly focussed on this area because the Plan Vélo only covers the inner city (Najdovski, w. d.). The case area has 2.2 million inhabitants as of 2023, spans an area of in total 105km² and has a population density of 20.000 people per km² as described before.

Research aims of cycling model

The covid-19 pandemic, as described before, allowed for a growth in cycling infrastructure in many cities in Europe causing a spark in methods and applications of cycling networks. The differing methods that governments took show missing unity in guiding principles for establishing cycling networks. For the effective implementation of cycling networks in cities the plans need to be executed strategically and holistically. However, many cities struggle with the implementation of the cycling networks. In most cases the cycling networks must be shoehorned in the existing road network causing coercion. Wysling & Purves (2022) notes that developing methods to assess the current bicycle network and the impact of potential improvements to individual street segments to the network could provide useful guidance in the development of cycling infrastructure. Methods for developing bicycle networks by Lovelace underline the importance of careful planning with bicycle infrastructure planning (Lovelace, et al., 2017).

Bikeability and bicycle suitability

Cycling infrastructure varies greatly in morphology and attractiveness for cyclists. The quality of the cycling infrastructure can be defined by many standards like safety, directness or attractiveness. In this research the model distinguishes between *bicycle suitability*, measured at the level of individual street segments level and *bikeability* which is defined as the potential of a region to encourage cycling based on its accessibility and connectivity. The latter therefore is combining the bicycle suitability with the potential trip density based on destinations (Wysling & Purves, 2022). These two categories follow subsequently the supply and demand logic as described in the theoretical section. Wysling & Purves (2022) combined the two, as advised by Rybarczyk and Wu (2010), to allocate most effective improvements to the cycling infrastructure network based on the current streets.

Methodology and materials

The methods employed by Wysling & Purves (2022) consist of three main steps.
The first step focuses on preprocessing the data to make the data capable of generating a bicycle network for the case area. The step following this uses these data sets to model a network of suitability. For this several variables are recoded to ensure compatibility in later parts of the network analysis. The second step, a potential origin destination route analysis is constructed for a city-wide analysis for cycling demand. These steps combined, follow the logic of supply and demand and aim to allocate places in the case area for most effective potential improvements.

5.1 The materials and the pre-processing steps

The methods of Wysling & Purves (2022) used two primary data sources: OpenStreetMap (OSM) and data from Atelier Parisien d'Urbanisme (Apur). OSM data was used in line with the aim of the study of the data being globally available and open licence. Analysis of the OSM dataset on cycling routes found missing cycling infrastructure and therefore the dataset was combined with the extensive cycle path dataset of Apur.

To create a complete network, the OSM street network was merged with the additional information from the Apur dataset using OSM IDs. The following categories of datasets were used for the analysis: roads, cycle paths, waterbodies, parks, districts, elevation map, public transport data and a point of interest dataset as shown in Figure 18.
The dataset with waterways was used to exclude the elevation caused by the main river, the Seine. Park data was primarily used to exclude roads and cycle paths from being calculated through major parts since the aim is to cater to non-recreational cyclists. A dataset on districts was used to crop all other dataset to the case area. The elevation map, based on a DEM profile of the region, was used to calculate slopes on which segments of the roads were labelled with a value. Public transport and POI data was used to access destinations for potential trips. The roads and cycling infrastructure dataset were cut at intersections resulting in separate road segments.
Each street segment of the resulting dataset represented a unique segment with uniform characteristics based on the available data.

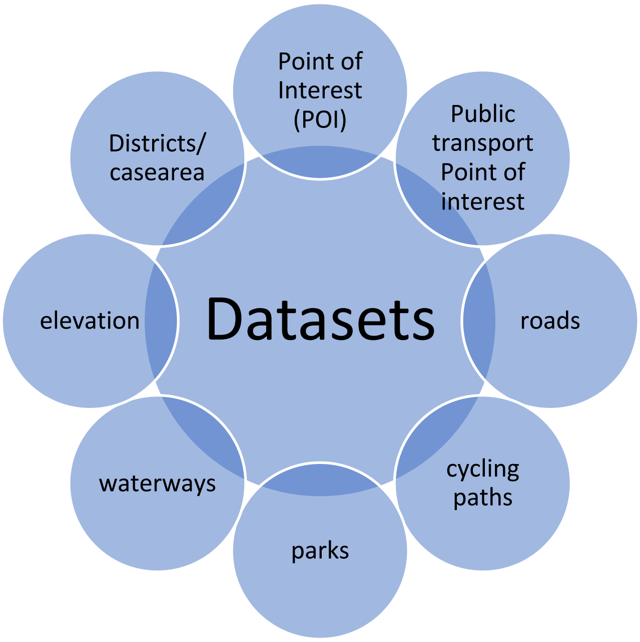

Figure 18: Datasets used for the analysis

5.2 Bicycle suitability

Bike suitability is a term that describes the perceived comfort and safety of a street segment (Lowry, Callister, Gresham, & Moore, 2012). For the analysis of routes, the shortest routes between origin and destination are taken in this research following the methods of Wysling & Purves (2022). Factors causing deviation of the shortest routes have been found to be factors like travel time, slope, traffic volume speed limit, type of intersection and presence of cycling infrastructure. Analysis of these factors influencing the route choice found that avoiding high traffic situations and reducing overall travel time were the most important factors for deviation of the shortest route. High vehicular traffic flows in combination with lacking bicycle infrastructure showed strong deviation of route choice. In addition to this the slope of a road segment was also a determent. Slopes of 2% were often avoided while slopes of more that 6% were almost always avoided (Broach, Dill, & Gliebe, 2012).

The complexity of these factors and how to model them requires the categorisation of suitability. The paper of Wysling & Purves (2022) subsequently combined the speed limit and the type of infrastructure for cyclists following the methodologies of Lowry *(2012*). The DEM profile was used to calculate the slope of the road segment by first finding the highest part of the segments and calculating the slope as a result. The slope was given in percentages as methodology of other papers also used percentages to indicate the slope. The percentages were allocated to slope numbered categories to be used in the bicycle suitability section. The slopes were categorised in six categories. The bicycle suitability of road sections was allocated based on the slope, type of infrastructure, car lane max speed in the following formula: $ps = ds\ (MSuitability, s + MSlope, s)$
Wherein the ps is the value used in the network analysis for the bikeability and for allocating improvement sections and suitability was derived from the bicycle facilitation per segment and slope to calculate the slopes. The ps is the perceived distance which combines actual distance and the factors that make the trip more difficult such as slopes and type of road segment.

5.3 Bikeability

The level of bikeability is defined by Wysling & Purves (2022) as the potential of a region to encourage cycling based on two factors, connectivity and accessibility to important destinations in the city. This is evaluated over the segments of bicycle suitability that were created in the previous steps.

Destinations were selected from the Points Of Interest and public transport points dataset. The following categories were included: leisure activities, education, shopping, city functions and public transport stops. Here, choices based on the context and data availability can affect the selection, as also indicated in the Rscript.

The connectivity and accessibility are affected by the route's bicycle suitability and reachability. Following research from Graz, Austria, the bicycle accessibility is defined as bicycle friendliness of street segments, not the possibility to cycle there since most places are accessible but not desirable for cycling in urban context (Krenn, Oja, & Titze, 2015).

The bikeability was calculated based on the shortest paths between origins and destinations in the network of streets. Following this step, the case area was overlaid by a 250m raster on the network following the methods used by Larsen et al. (2012). Wysling & Purves (2022) used locations of origins and destinations as network nodes with the highest centrality in each raster cell.

The POI dataset was used as destination, thereby assuming an equal distribution of origin across the case area. Comparing the bikeability map with the destination raster can reveal paths that can be improved. The methods of Wysling & Purves (2022) were followed when possible, however since the data availability differed for the case area in Bangkok modifications were necessary. Since the modifications were case specific it was deemed appropriate to discuss them separately from the general methods of the model of Wysling & Purves (2022).

6. Bangkok case specific methodology

Introduction

The methods developed by Wysling & Purves (2022) were aimed to be universally applicable to cities in general, the variation in data availability and differences in the context required adaptations to the methods for Bangkok. Most of the datasets required for the analysis developed by Wysling & Purves (2022) were available though some were incomplete or missing and therefore modifications were made to accommodate the difference in data availability. Multiple models have used a similar methodology, with modifications to the variables to assess both the supply and the demand sides of the network (Cabral, Kim, & Shirgaokar, 2019).
Therefore, it was considered appropriate to make informed changes to the model based on the specific context and requirements as will be discussed in this section.
First, this paragraph will focus on the availability and sources of the data. After that the quality of the data will be discussed followed by a description on the steps taken as preparation to the data analysis.

6.1 Sources of data for Bangkok

Geodata of NEXTGIS was used, substituted with data from Cycle OSM. Cycle OSM is a non-profit open-source initiative to map cycle infrastructure based on OSM maps. The Cycle OSM dataset is popular because it is widely available in open licence similar to the data source used by Wysling & Purves (2022). Data on roads in the city of Bangkok was available however the categorisation was not elaborate enough that it included the speed limits of all the roads.
The cycling path data, Cycle OSM, was geocoded and therefore usable though did not describe the type of cycling infrastructure. Other sources such as a GitHub sourced dataset by Kanawattanachai was also found, though was less useful since it was written in Thai (Kanawattanachai, 2022). In deviation from the methods of Wysling & Purves (2022), the type of infrastructure data was selected as a means of determining bicycle suitability. The implications of this choice will be further discussed in the results section.
For the elevations a DEM model was used like the methods of Wysling & Purves (2022) though from a different source, EOSDIS Earthdata, since the data in the study of Wysling & Purves (2022) was retrieved from a dataset that did not extend beyond the boundaries of France (Wysling & Purves, 2022).

While some data for Bangkok specifically included Thai, the translations in English were also available in separate columns making the data usable for a wider audience. Most sources of data are made available through researchers of local universities while little information was supplied by the governmental institutions. This was in contrast with the research of Wysling & Purves (2022) that relied mostly on governmental institutions for the geodata. Whether the data that was used in this project was originally gathered by the governing institutions of Bangkok or the national government is unclear. The open data availability and planning documentation by the Thai authorities was low. A local researcher with experience in doing research on cycling in Bangkok was contacted on the availability of geodata that was missing though to no avail indicating rather a lack of datasets than a language barrier as a reason for the lacking data.

Quality of the data used

The sources of data in this study were not always as recent, some dating back to 2013, compared to the sources used by Wysling & Purves (2022) though as I was confined to the small number of sources of data the most suitable and most recent data was used in this project.

In the case of Paris, the data was required to be recent since the infrastructure had changed extensively due to its earlier described policy. This however is less the case for the central districts of Bangkok since infrastructure had only been changed marginally, especially cycling infrastructure as recent research had suggested (Panthasen T. &., 2016; Panthasen, Lambregts, & Leopairojana, 2020).

6.2 Modifications to data, case specific

Population and case area

The case area, inner city Paris, in Wysling & Purves (2022)'s study was defined based on political borders, similar to many metropolitan areas. In Paris the inner city is governed by one municipality creating the uniformity of policy and the urban fabric since these districts all follow the same policy. Bangkok in this regard, deviates since it does not have a clearly defined central area. To accommodate, as described before, centrally located districts were selected, adding up to a comparable population size.

Centrally located districts offer inner city densities that towards the edges are considerably lower similar to Paris. Next to that, the outer districts, with increasingly large building blocks are increasingly unfavourable for cycling.

Pre-processing steps

The first sections of the script are related to setting up the data sources. Early in the script the coordinate system and projection were set. In this step only the epsg number was changed for the region of Bangkok.

The section preparing the datasets for analysis required some modifications since the names and column numbers deviated. In this section relevant columns are selected out of the geodata set and are pre-processed to be used at a later stage in the analysis. All data was set to the same projection and the datasets were cropped to the borders of the case area.

The roads dataset however was found to be altered in the crop prosses to a different geometry, from sfc_LINESTRING to sfc_GEOMETRY. For this reason, the cropping of the roads was moved after the section that removes the main river from the slope analysis since the sf_intersection function was not able to perform on a sfc_GEOMETRY dataformat.

Next to that, often merging with rows, selected by numbers rather than names, proved to be difficult since the methods of Wysling & Purves (2022) did not accommodate the differences in columns.

Cycling dataset addition

In the original dataset on cycling infrastructure used by Wysling & Purves (2022) extensive categorisation of cycling paths was included. This dataset included the type of path indicating the attractiveness and quality of the cycling path. Subsequently this data was used in the analysis to attribute a value to each segment. For the context of Bangkok this categorisation was not available. As a substitute the data on types of cycling paths was generated by using Google Street view to find the paths and evaluate the type of cycling path. As a result, the selection on type was changed to a selection on osm_id since the dataset as described before was incomplete. Similar methods of allocating typology to street fragments were used in research on Graz and Copenhagen for bikeability of the cities (Krenn, Oja, & Titze, 2015; Mekuria, Furth, & Nixon, 2012).

While this was possible in the context of Bangkok since the dataset of cycling infrastructure was relatively small, with bigger datasets and in situations where street view is not sufficiently available this could be a problem in the model.

Speed limits

The geo dataset of the roads, despite being extensive, only indicated the speed limit of the roads on less than 1% of the roads. In the methods of Wysling & Purves (2022) the speed limits were used to allocate suitability of potential cycling infrastructure. As a result of the data on speed limits in Bangkok being incomplete an alternative method was used. In this approach, the type of road, which was available for all roads, was used as an indicator of the speed limit. This method was adopted as a substitute for speed limits based on the assumption the type of road indicates similarly to the max speed its cycling suitability.

POI, different interests yet similar approach

Potential trips are calculated in the step bikeability. For the origin the assumption is that trips can start from everywhere in the city. As destinations Point of Interest data of OSM and the public transport stops were used. Here multiple categories are chosen with likely destinations. There was a difference in data as the categorisation differed, leading to modifications to the script to accommodate the available categories. Subsequently, choices must be made in what to include and what not to include yet since the author Wysling & Purves (2022) gave little attention to the choice of these POI's and the analysis focussing on travel behaviour in general the choice of categories are assumed to be not strictly limited to the used categories by the model. Therefore, categories were chosen on relevancy to the Bangkok area and similarity of the categories used by Wysling & Purves (2022).

Waterways and parks

The methodology, as mentioned before, included the removal of the main river of the city of Paris since the surrounding DEM profile would influence the calculations unintentionally. This step referred specifically to the Seine polygons of the water dataset, and thereby had to be changed to the context of the Bangkok case area dataset. Here the comparable main river of Chao Phraya was used. For the parks dataset case specific modifications also had to be made excluding the main parks in the context of the case area of Bangkok.

Preparations of the data

While the analysis of the geodata was performed in RStudio, the datasets were loaded in QGIS to analyse their quality and make maps that were not part of the RStudio analysis.

The analysis of the DEM dataset, on which slopes were calculated of the road segments, showed that the area had little elevation as literature also had suggested.

7. Results and findings: case study Bangkok

The findings on the model of Wysling & Purves (2022), as a tool for analysing cycling infrastructure, will be discussed in this section. The methodology and variables used by the tool were compared to similar tools and findings in literature. The variables and methods used in the model of Wysling & Purves were in many cases similar to variables used in similar tools. The methodology is predominantly based on established methods and models. Therefore, the methodology of the model was found to be extensive with the use of established theories and the use of detailed data. The latter however, was in this study for the case area of Bangkok found to be unsuitable since the data available on the case area was insufficient for the model to function. Subsequently, the lacking data and results will be discussed here.
The table below, Table 3, indicates the data incompatibilities encountered with the analysis on the case area of Bangkok.

Table 3: Dataset incompatibility for the model of Wysling & Purves (2022)

Dataset	**Missing/ required change**
Case area	Select case area
Cycling infrastructure	Missing type of cycle path
Roads	Missing maximum speeds of roads
POI	Deviating categories of Points of interest
Waterways	Change to relevant waterway
Parks	Change to relevant parks

As mentioned earlier, the incompatibility of the data required significant modifications to the script to enable the model to run successfully. These changes, outlined in the methods section, primarily involved altering names, references, and implementing alternative methods in certain data processing steps.
In the model, the case area was changed from the case area in Paris to the case area of Bangkok as described earlier.
The dataset of current cycling infrastructure was replaced by a comparable dataset for cycling infrastructure for the case area of Bangkok. Further modifications had to be made because the dataset for Bangkok was missing data on the type of cycling infrastructure. Therefore, the type of infrastructure was based on Google Streetview observations that were translated in a categorisation of cycling infrastructure. Without this modification the allocation of suitability of the cycling paths would not have been possible.
Data on the roads was similarly missing a category relevant to the analysis, the maximum road speed was absent for most of the roads in the dataset. After changing the roads dataset for the Bangkok specific roads dataset the allocation of suitability of road segment was modified from speed based to type of road. Therefore, it assumed speed and road type to be similar for this analysis.
The methodology for POI, Waterways and Parks were case specific to the Paris case area and therefore modified to match with similar data for the case area of Bangkok.

Despite numerous attempts to address issues by consulting experts and utilising online resources, the analysis was frequently halted due to errors. It is possible that the introduced changes contributed to these errors during the model's execution. While further more extensive modifications could have been made in an attempt to resolve the occurring issues, it was decided to adhere to the study's objective of testing the model's applicability apart from its original case area, with the aim of testing the model's claimed generalisability.

8. Discussion of the relevance and applicability of this tool

The aim of this study was to test the applicability and relevance of a tool for cycling infrastructure improvements by Wysling & Purves (2022) from a European context on a city in a developing nation.
Subsequently, the question was if the model of Wysling & Purves (2022) based on Paris would be applicable to other cities.
The analysis of the case area of Paris and Bangkok described the areas as relatively comparable in relevant geographic and demographic characteristics. Past mobility trends of Paris were comparable with current trends in Bangkok with high private motorised trip shares and subsequent congestion and infrastructure. The analysis revealed that the policy of Paris was extensive and complied with most of the~~, in the theoretical perspectives described,~~ best practices for the enhancement of cycling including extensive network-oriented development focussing on demand. The relevance of a wide scope for the measures of the stimulation of cycling in the urban context was shown by both the theoretical perspectives chapter and the policy analysis of the case area in Paris. Both chapters also found that developing an extensive network of cycling infrastructure, where the model of Wysling & Purves (2022) can play a role, is of great importance to the process of cycling stimulation. This is mostly because it increases perceived safety, the most important determinant for people to cycle. The most vulnerable and decisive phase is the start when investments must be made while results and subsequently public support remain low. Especially in developing countries, where car ownership grows most and budgets of cities are most compromised, this phases is the most difficult phase.
The policy of Bangkok was found to be substantially less elaborate with fragmented policy and only meeting few of the theoretical best practices like ride share and a few bicycle lanes. Subsequently, the cycling network and trip shares are almost non-existent in Bangkok's congested streets. Moreover, the cycling infrastructure is not developed with a larger network-oriented development pattern in mind since mostly unconnected fragments were built.
Based on the physical characteristics, there are no clear limitations found for Bangkok in developing cycling infrastructure and subsequent rideshares comparable to inner-city of Paris since the areas are mostly comparable. Therefore, the successful methods used for Paris have high chances in being successful for the development of more cycling infrastructure in Bangkok.

The model of Wysling & Purves (2022) was found to use relevant variables and methods for analysing the demand and supply side of cycling infrastructure. For this model the datasets used by Wysling for Paris were available in high quality and with great detail allowing for a detailed and reliable analysis. However, for Bangkok the geodata was not detailed enough to match the requirements of the R analysis. Subsequently, adaptations were made to accommodate for the lower data availability, yet to no avail.
Instead of pursuing further even more extensive modifications to the model to address these issues, a deliberate decision was made in line with the study's objective of evaluating the model's relevance and applicability for analysing cities beyond the original case area of Paris.
As a result, the model of Wysling & Purves (2022) was found to be inadequate in creating a network-based analysis of the case area in Bangkok. Therefore, the universal applicability of the model is not supported by this study.

Available data and policy documents found for the area of Paris were considerably more extensive compared those of Bangkok. Relevant data on the case area of Bangkok was mostly derived from international studies, studies of local universities and international agencies while for Paris governmental institutions already provided sufficient data. While this difference can be explained by the government not publishing much of its, for this study, data and policy. However, my inability to read Thai could have also contributed to missing data and documents. In some cases, Thai contacts, among which a researcher on mobility in Bangkok, were consulted for finding the required data, yet they also did not succeed. Subsequently, while the language barrier might have been a barrier for finding might have played a role in my study, its impacts of on the overall findings might not have been substantial.

The model of Wysling & Purves (2022), as it was an approximation, also had next to the considerations discussed in the conceptual framework its limitations.

The model of Wysling & Purves (2022) focused on road segments, yet left intersections out of the calculations, while these have been proven to be the most dangerous components. Therefore, this is a clear limitation of the model. Next to that, the context specific value and function of variables like the public transport and POI's were assumed to be equal while this is not in line with literature and therefore a minor blind spot in the model. Furthermore, as described by Wysling & Purves (2022), the trip modelling does not model intrazonal trips nor does it account for temporal and individual components of accessibility.

9. Conclusion, implications and contributions of this study

The aim of this study was to test the applicability and relevance of a tool for cycling infrastructure improvements by Wysling & Purves (2022) from a European context on a city in a developing nation.
For this study the hypothesis was the following. The case areas, Paris and Bangkok, where expected to be comparable in for the model relevant variables yet deviate in its policy and use of tool as a means of increasing cycling rates. While methods to enhance cycling in the urban context are wider than the model, the model of Wysling & Purves (2022) was assumed to give a valuable contribution to the analysis of the cycling network in Bangkok since it is based on strong variables in assessing cycling routes and uses reasonably accessible data.

The comparison of the case area of Paris and Bangkok focussed on relevant variables discussed in either the theoretical perspectives or the model.
The comparison revealed the two case areas to be comparable, despite differences in size and elevation. Furthermore, Paris showed resemblances to the current mobility state of Bangkok in its car dependency and cycling policy and subsequent cycling share. The later policy of Plan Vélo 2015-2020 however, deviated strongly and was found to resemble many of the best practices described in the literature and case studies.
This in strong contrast to Bangkok where policy and tools still are unable to alleviate the low cycling share in mobility. Consequently, the methods and tools used for Paris can be useful in the case area of Bangkok.
Following the theoretical framework and the findings, the relevance of the model of Wysling & Purves (2022) was found to be impactful for effectively developing networks for increasing cycling rates. The findings of this study show the relevance of a model to analyse and guide cycling infrastructure for the stimulation of cycling in the urban context. Next to that, this study has provided a holistic overview on important considerations when developing such a network analysis tool. On top of that, it tested the applicability of the promising tool of Wysling and Purves (2022) and provided feedback on its applicability to the context of Bangkok.
The level of detail of the data required for the analysis did not match the level of detail of the openly available datasets making the model incapable of generating results for the case area of Bangkok. The ability of the model for the case area of Bangkok to generate results was therefore unsuccessful, refuting the assumed applicability Bangkok. Therefore the authors claim for universal applicability was not supported.
However, the aim and methods of the model are promising and its selection of variables for the calculations could serve as inspiration for other models that could be used in the case of Bangkok. The methods of testing the model used only Bangkok as case area, and therefore is limited in to concluding on the applicability to the case area of Bangkok. Therefore, it is beyond the scope of this study to conclude on the applicability on a wider set of cities in developing and developed nations however it is not unreasonable to assume similar levels of relevance and applicability depending on the data availability.
The societal relevance of developing best practices for the implementation of cycling in urban contexts is increasingly important. Especially for developing countries, where car ownership grows fastest, the effective implementation of sustainable means of transport is of great relevance.
Methods and tools for cycling stimulation in urban contexts are more frequently developed for the developed world. The information of their applicability for nations with developing economies is lacking.
Therefore, analysis of the applicability of the methods and tools for developing economies is relevant in establishing best practice for these contexts and this is where this study contributed to science and society.

Recommendations

With the aim of supporting the development of methods on increasing cycling rates in cities in general and the development of cycling infrastructure models in particular several recommendations can be made based on this study. The development of tools and other guiding models for the development of cycling in cities is promising though must not be seen as a value neutral assessment. For the broad generalisability of the model of Wysling & Purves (2022) more cities need to be tested on the applicability of the model.

For the model of Wysling & Purves (2022) and its application to the city of Bangkok it is recommended to adapt the script to accommodate the data availability of Bangkok.

Further testing on other cities in developing nations will be needed to form a better understanding of the context specific requirements.

This study aimed to contribute to the development of methodology of increasing the cycling share in urban contexts. Most research on models and tools for the implementation of cycling in urban contexts is developed for and in Europe. This study deviated from this by testing a promising tool developed in Europe on a city, Bangkok, in a developing nation. The case study described the urgency for methodology by describing the current situation and the insufficiency in current methodology. Therefore, this study contributed to the development of methodology of increasing the cycling share in urban contexts, with a specific focus on Bangkok. Methods for creating cycling-friendly cities are still undergoing development, yet already offer promising approaches. More importantly, this development paves the way for an inspiring future characterised by safer, more liveable, and aesthetically pleasing urban environments.

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Appendix

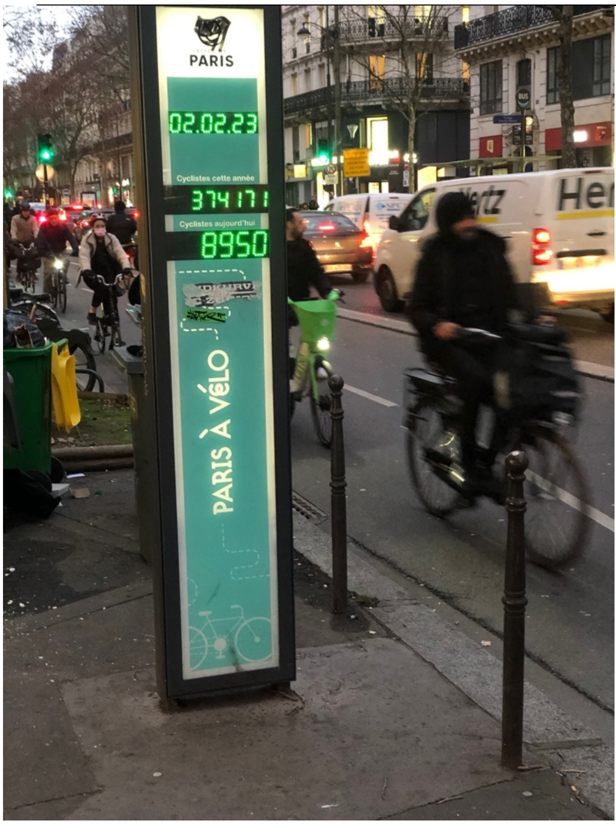

Figure 19: bicycle counter in Paris, Boulevard de Sebastopol, photo by author (2023)

Figure 20: bicycle parking, a key feature in cycling policy yet with extensive growth hard to keep up, photo by author (2023)

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Figure 21: Velib' docking station with rental bicycles located next to a six lane arterial road without bicycle lane near the ring road, photo by author (2023)

Figure 22: New cycling infrastructure takes car space but frees space for cyclists, photo by author (2023)

Figure 23: Theory to practice, there is a lot of learning by doing involved, here confusing lines and a dangerous signpost in the cycle path near Canal Saint Marti, Paris, photo by author (2023)

Figure 24: Dedicated protected cycling lane, the "holy grail" of cycling infrastructure in green, Paris, photo by author (2023)

Figure 25: Rush hour in Paris makes car traffic so dense that cyclists use the pavement as their path, not ideal but possible and common in Japan, photo by author (2023)

Districts

Table 4: Districts of Bangkok relevant to the analysis source: (Open Street Maps (OSM), 2022)

district number	English name	population
1	Phra Nakhon	60
2	Dusit	110
4	Bang Rak	50
6	Bang kapi	150
7	Pathum Wan	50
8	Pom Prap Sattru Phai	50
12	Yan Nawa	80
13	Samphanthawong	30
14	Phaya Thai	70
15	Thon Buri	120
16	Bangkok Yai	70
17	Huai Khwang	80
18	Khlong San	80
25	Bang Phlat	100
26	Din Daeng	130
28	Sathon	80

30	Chatuchak	160
31	Bang Kho Laem	90
33	Khlong Toei	110
34	Suan Luang	120
37	Ratchathewi	70
39	Watthana	80
45	Wang Thonglang	110
29	Bang Sue	130
Sum		2180