MRP-Songxin Liu-Urban Street Evolution The Opportunity from Emerging Transportation Technologies to Create More Human-centred Places

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MAJOR PROJECT:

Urban Street Evolution: The Opportunity from Emerging Transportation Technologies To Create More Human-Centred Places.

(Songxin Liu)

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Being a Major Project in Urban Design and City Planning (course) submitted to the faculty of The Built Environment as part of the requirements for the award of the MSc (course – Urban Design and City Planning) at University College London,

I declare that this project is entirely my own work and that ideas, data and images, as well as direct quotations, drawn from elsewhere are identified and referenced.

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URBAN STREET EVOLUTION:

THE OPPORTUNITY FROM EMERGING TRANSPORTATION TECHNOLOGIES TO CREATE MORE HUMAN-CENTRED PLACES.

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CONTENT

List of Figures and Tables:

ABSTRACT

With the rapid population growth in cities, the existing transportation system exposes insurmountable problems due to restrictions of conventional technologies. In this circumstance, some emerging transportation technologies become potential solutions, while relevant research is mainly from the domain of engineering and information technologies. From the perspectives of city planners and urban designers, this research aims at exploring the question about how can street design response to the advent of those new technologies and regard this transformation as an opportunity to revive street life. By identifying the key features of four main technologies: autonomous vehicles (AVs), automated mass transit, shared bicycle or scooters, and better delivery systems, this research tries to find out proactive alteration of streets to accommodate those elements and become more human-centred spaces. A tool-kit, which consists of five tools, shows the spatial design guidance for different circumstances on streets and the deployment of street facilities. The tool-kit is applied in a specific site in Tianhe Central Business District in Guangzhou, China. By examining the proposed tool-kit and demonstrating the possibility of embedding those transportation technologies into our urban environment, this research presents a probable prospect of vibrant, versatile, safe and resilient streets, which contain multiple transport modes and support our urban life.

Keywords: intelligent transportation; street design; autonomous vehicles; automated mass transit; shared bicycle; delivery system.

INTRODUCTION

1

Transportation is one of the most crucial activities in cities (Corbusier, 1943). We have been finding better ways for mobility, which is the fundamental desire and need for human (Norberg-Schulz, 1971). A hundred years ago, automobiles powered by internal-combustion engines and fossil fuel were invented and soon replaced horse-drawn vehicles (William, Christopher and Lawrence D. Burns 2010). In the past century, diverse automobiles have been serving cities by transiting people, goods and services and keep metropolises working and growing. However, because of its intrinsic features and surging transport demands in urban areas, the shortcomings of conventional transportation system have become more and more conspicuous while facing rapid urbanisation and exploding population. A new generation of transportation system is coming and expected to be the solution of existing predicaments such as congestion, fossil fuel shortage, greenhouse gas emissions, traffic accidents and parking occupancy (Litman, 2015).

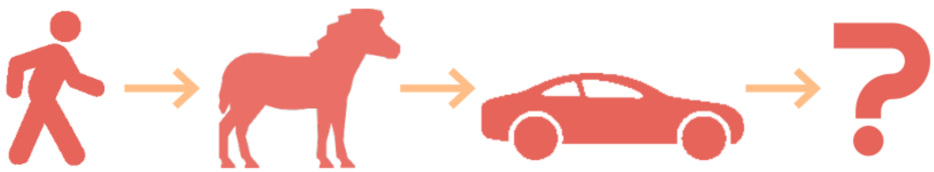


Fig. 1.1: The evolution of human mobility.

Research Question

How can urban streets respond to the advent of intelligent transportation technologies and become more human-centred spaces?

In the past two decades, appearances of innovative transportation have been coming into the public eye and betokening the advent of transportation system transition (Fishman, 2014). This system consists of several components: innovative vehicles, energy supply, street and road infrastructure, land use pattern, market mechanism and policy groundwork (Mitchell et al., 2010). Among those constituents, street infrastructure are comparatively lagging behind the others (Fishman, 2014). The modified street spaces are supposed to accommodate those new vehicles and adapt to new urban lifestyles. On the other hand, this is also an opportunity for urban streets to become more vibrant and versatile by providing flexible and human-centred space (NACTO, 2017).

However, research and studies predominantly concentrate on the working and operating mechanism of transport technologies and they are usually driven and lead by transportation manufacturers such as Airbus, Tesla, Audi and Toyota or high-tech company such as Alphabet and Uber (Fishman, 2014). There is little research referring to potential alteration of transportation infrastructure. That results in the sluggish reaction on the infrastructure side while comparing to the vehicle side(Bishop, 2011). This research tries to fill in this research gap by discussing the reasonable transportation deployment and probable urban street configuration from the perspective of urban design when those innovative technologies are adopted in future.

Therefore, researching and exploring probable prospects of urban street evolution coming with intelligent transportation has practical significance. It is a response to the evolution of contemporary transportation from urban design and planning.

Problems of Existing Transportation

In the past century, the progress of transportation industrial enhanced personal mobility and extend the accessible scope of human being. According to report from UN (UN News, 2008), it is estimated that over 70% people in the world would live in urban areas by 2050. The exploding urban population and growing demands of commuting bring huge pressure to the transportation system and expose four inevitable problems.

Space Occupancy

35-50%

Land-use proportion of roads and parking lots in automobile dependent cities (Rodrigue, 2017).

96%

The proportion of time that private cars stay parking (Bates and Liebling, 2012).

Those single-use places deprive urban land which was supposed to be used by all inhabitants and make them become vehicle-centred spaces. Low rate of usage makes existing transportation unsustainable and inefficient.


Fig. 1.2: Parking Lot in Atlanta. Source: Atlanta Business Chronicle.

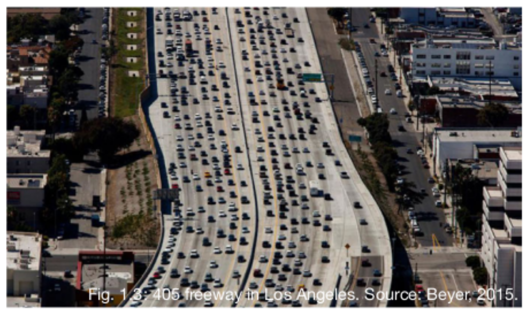


Fig. 1.3: 405 freeway in Los Angeles. Source: Beyer, 2015.

Pollution[1]

(Data Source: Mitchell et al., 2010)

18 million barrels

Oil consumed for driving cars everyday in the world.

2.7 billion tons

Carbon dioxide emitted to the atmosphere each year.

0.36 %

The proportion of electric cars in the world in 2017.

Most of vehicles now are still powered by internal combustion engines and energised with petroleum. The street becomes an unfriendly space to stay and stroll because of polluted air and annoying noise.

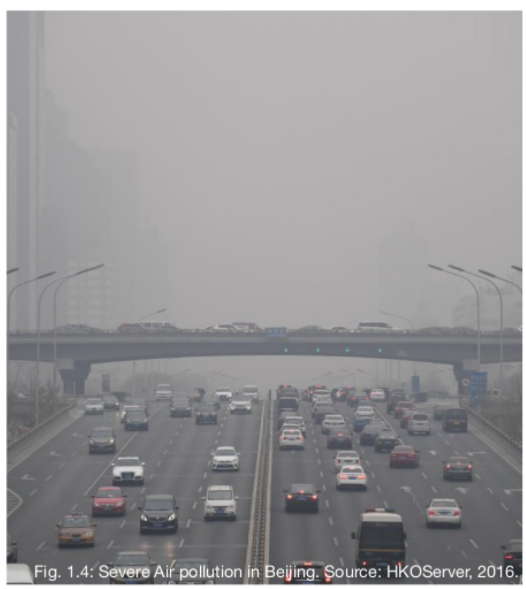


Fig. 1.4: Severe Air pollution in Beijing. Source: HKOServer, 2016.

Congestion

(Data Source: Mitchell et al., 2010)

850 million

The sum of cars and trucks worldwide.

<10 miles per hour

The average speed of vehicles in dense city centre

34 hours

Average time that a commuter spent on traffic congestion in 2010 in America. The number of that in 1982 was 14 hours.

$100 billion

The annual cost of congestion in America.
(Data Source: Mitchell et al., 2010)

The low usage rate of personal vehicles results in the high volume of car ownership and congestion problem. Commuters spend more and more time and money on their ways to the destination instead of the destination itself.

Fig. 1.5: Traffic Congestion in America. Source: Shellenbarger, 2016.

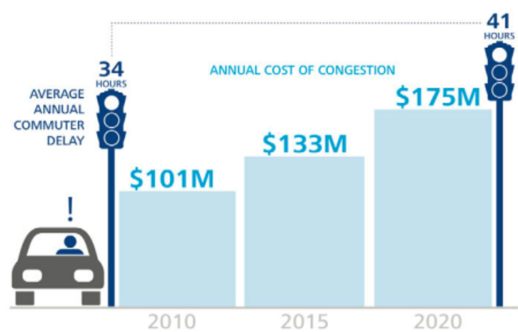


Fig. 1.6:
Annual cost of congestion in America. Source: Mitchell et al., 2010.

High Use-cost

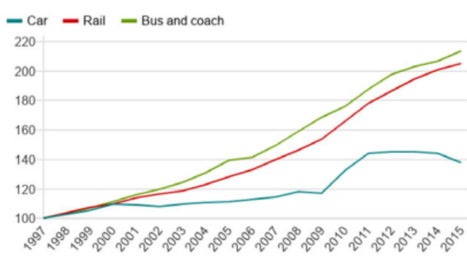


Fig. 1.7:
The increment of transportation cost in Britain (in %)
Source: Department for Transportation, UK

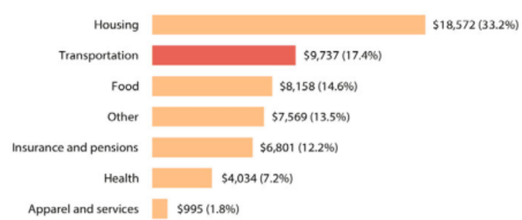


Fig. 1.8:
Transportation expenditure ranks the second in all categories of household cost in US, 2017
Source: U.S. Department of Labor Bureau of Labor Statistics, 2017

The increasing transportation cost constrains people's expenditure on other categories such as food and recreation, which could reduce the quality of life.

Benefits of the New Generation of Transportation

Widely Connected

Vehicles in future will become part of an integrated and sophisticated transportation network. The nexus among vehicles, passengers, infrastructure, service providers, road facilities and the interaction between different vehicles are the essence that makes the transportation autonomous, which is considered as the key to tackle congestion (NACTO, 2017).

Electrified

More and more countries including France, China, Korea, Germany and America have restricted the use of petrol vehicles and encourage electric cars (Rolandberger 2018). Besides its contribution to sustainable development, the electrified vehicles also possess advantages such as smaller size and quieter operation.

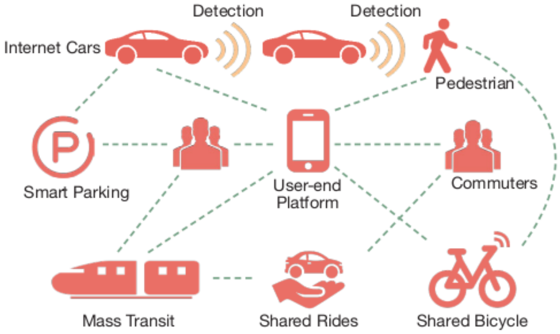


Fig. 1.9: Widely connected transportation system.

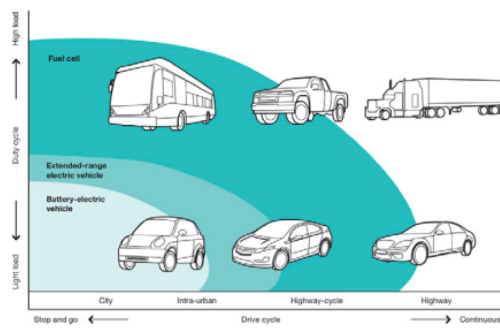
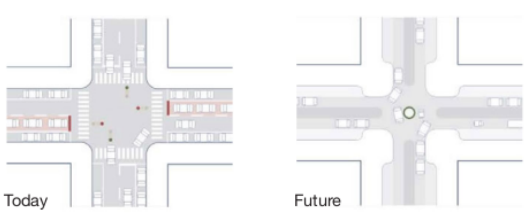


Fig. 1.10:
Application matrix of electric-drive vehicles. Source: Mitchell et al., 2010.

More Efficient

Due to frequent information exchange, real-time traffic condition monitoring and adjustment become feasible. Autonomous vehicles can reduce traffic congestion significantly and make transportation much more efficient and safer by communicating with each other.

Fig. 1.11: Traffic flows at different junctions.
Source: NACTO, 2017.



More Accessible

The big data collected from numerous sensors and vehicles can integrate different traffic modes and distribute the transport resources reasonably. The commuting will become more accessible by multiple transportation choices with lower cost (Litman, 2019).

Fig. 1.12: Multiple modes.

A Solution to Tackle the Problems

According to the relevant research and literature (e.g. Fitchard, 2012), new generation of transportation features not only sustainable energy source but also the competence of high-level autonomy. More importantly, with significant changes in developing industry, the new transportation focuses more on people throughput instead of vehicle throughput. Thus, the passengers and commuters will substitute for cars to become the main characters of transiting in this human-centred framework (Fishman, 2014).

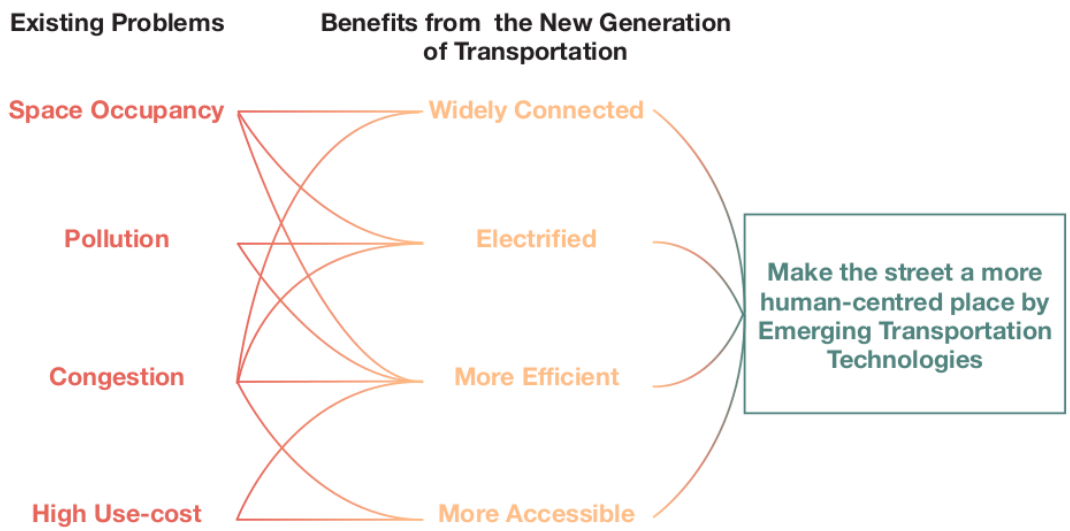


Fig. 1.13: Relation between problems and benefits.

Research Objective & Contribution

The transformation of transportation infrastructure is not a passive assignment but a proactive attempt to revive street life in the digital age.

This research aims at making a proactive response from the viewpoint of urban designers and planners. It is not just about making the infrastructure adapt to new technologies but also exploring the contribution beyond those technologies and endeavouring to reclaim the street spaces. Streets could be converted from places just accommodating cars and trucks to vibrant public realms, which encourage social interaction and various activities. Three objectives are expected to be accomplished:

- Creating vibrant and versatile public realm on streets;
- Building safe and resilient street environments;
- Creating an integrated transportation network that keeps pedestrians and vehicles flowing more efficiently and continuously.

Those three objectives are based on the human-centred design principle and supported by emerging transportation technologies.

This report tries to comprehend how transportation infrastructure will look like and how they can collaborate with other components such as vehicle engineering, policy and regulation frameworks in this synergistic process. More precisely, its contribution focus on three aspects:

- Design guidance for different types of street spaces;
- Deployment and utilisation of street facilities;
- Street management and operation advice.

Three Objectives

Vibrant & Versatile Public Realm

More space on streets is released due to the promotion of traffic efficiency and streets become more quiet and clean thanks to electric power. Streets are converted into accessible and delightful public realms.

Safe & Resilient Street

The road fatality will decline through the deployment of detectable vehicles and more intelligent monitoring system. By more efficient space utilisation, street layout is readjusted to promote its resilience for coping with harsh condition.

Integrated Network

Through integrated and real-time information of different traffic modes, the transfer among them becomes more seamless and user-friendly.

The Research Problem

Research problem:
Existing infrastructure are not ready to greet the advent of new transportation system.

Research and investigation about the situation of existing transportation systems indicate that the present transportation infrastructure are not able to adequately match the requirement of new transport modes. There are two interrelated aspects which obstacle or influence the development of new transportation: existing infrastructure and current policy frameworks. The relevant policies, regulations, design guidance and principles which determine the street form are serving for the conventional transportation system. As a result, the advancement of transportation infrastructure lags behind the other components in this revolution.

Deficiencies of the Existing Transportation Infrastructure

In most countries, roads are spread wider and wider while pavements are shrunk and street life is eliminated (Sadik-Khan, 2017). Generally, the following elements of infrastructure are missing now, which hinders the development of new transportation:


Fig. 1.14
Busy and inefficient intersection in China. Source: Wu, 2018.

Smarter Intersections

An autonomous and adaptive traffic light system can adjust signal phases by communicating with surrounding intersections and analysing dynamic traffic condition. (Sidewalk Labs, 2017). Direct interaction with passing autonomous vehicles can create agile and reactive traffic network.


Fig. 1.15
Manual transportation management centre in New York.
Source: Chong, 2017.

Sensors & Intelligent Control Systems

Sensors for collecting real-time information are the foundation of data-driven transportation management. The existing TMCs (Transportation Management Centres) operated by humam will be replaced by more agile systems such as SCATS, SCOOT, ATC-Lite (Ng, 2017).

Dynamic Kerbs

The kerb is the most contested space accommodating diverse urban activities (Dawson, 2018). However, there are few regulations regarding the management of those upcoming dynamic kerbs.

Fig. 1.15: The kerb dominated by parking

Sufficient Charging Facilities

Wherever the electricity comes from, it will be transited into the vehicles by different charging facilities including domestic charging outlets and public charging stations. Both sufficient charging points and high-capacity electrical grids are indispensable to run this electric-drive system (Mitchell et al., 2010). For instance, Amsterdam is at the forefront of encouraging electric cars but it is still facing the charging point deficiency of 13,000 at least (Ren, 2019).

Fig. 1.16
Charging port in Amsterdam. Source: Storyblocks, 2017

Space for Shared Vehicles

With the rapid growth of shared vehicles, how to manage the conflict between their parking space and the occupancy of public realms is an inevitable issue. In China, Guangzhou has prohibited new deployment of shared bicycles to control their number (Wei, 2019). Sufficient and appropriate space for shared vehicles is the foundation of this sustainable transportation mode.

Fig. 1.17: Shared bicycle in China. Source: ifeng, 2017.

Integrated Platform

Seamlessly experience among multiple transportation modes requires an integrated platform that interlinks different mobility providers, diverse data sources, price inquiry, vacancy query and payment systems. Integration of traffic information is regarded as the fundamental element of Maas (mobility as a service), which is believed to become crucial mobility pattern in future (Dixon et al., 2019).

In-car operational system (such as Android Auto and CarPlay), connectivity standard (such as GTFS) and unified application programming interface (API) are necessary components. Although there are companies like Google and Car Connectivity Consortium are working on it, a unified and generic platform is still far away from practical application (Fishman, 2014).

Fig. 1.18
Two mainstream in-car systems. Source: Parsons, 2016.

Present Situation of Relevant Policy Framework

There are rapid technological innovations in the following three regions. As Regards regulation and standardisation, there is considerable progress in North America. Many states in America, such as Nevada and Florida, have launched relevant regulations to facilitate autonomous vehicles' (AVs) experiment and utilisation. However, on a worldwide scale, most countries do not have nationwide guidance, which confines the road test and further deployment of AVs (Frost & Sullivan, 2018). For instance, there are only six cities in China that allow the road test of AVs with limited time and place control (Zhao, 2019).

	Europe	North America	Asia
Technology Innovation	√	√	√
Regulation &Standardization	—	√	—
Nationwide Guidance	—	—	—
Value Chain Evolution	—	—	—

√ Own — Missing

Table 1.1: Developmental Assessment of Different Regions
Information Source: Frost & Sullivan, 2018

According to the report of *2019 Deloitte City Mobility Index,* which reviews the transportation development of 56 important cities in the world, there are 54 per cent of cities rated under "top performer" in the metric of "regulatory environment", which focuses on operation of ride-sharing, relevant regulations for innovative transport, support to AVs and future mobility strategies. In the other metric called "Innovation", there are 46 per cent of cities have not reach "top performer" or higher standard. This is the performance of the biggest cities in the world and it can be imagined that other smaller cities may also not ready for the new transportation system in terms of regulation and policy framework.

The research from MIT (Hudson et al., 2019) also reveals similar dilemma in the United States where has the most advanced and open policy framework for new transportation. It indicates that only 36 per cent of the largest cities have regulation or plan referring to AVs.

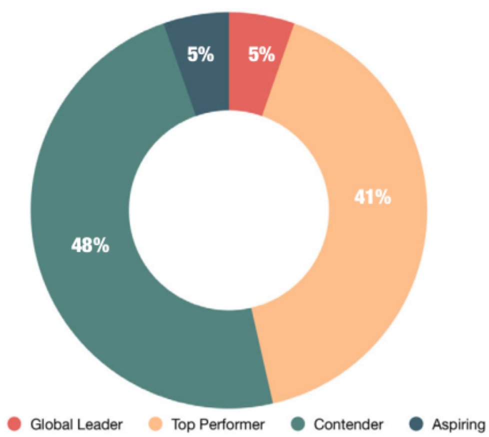


Fig. 1.19: Transportation Regulatory Environment Assessment
Information Source: Dixon, 2019

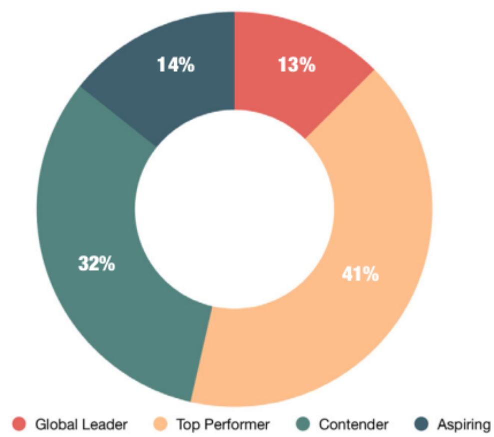


Fig. 1.20: Transportation Innovation Assessment
Information Source: Dixon, 2019

LITERATURE REVIEW AND CASE STUDY

2

Autonomous Vehicles

History of Autonomous Transportation

Fig. 2.1: History of Autonomous Transportation (Refer to appendix 1)

The development of formal autonomous vehicles dates back to 1950s when the RCA Labs tested their full-size system in the United States (Nancy, 2017). While it comes to 2000s, technologies of autonomous vehicles had great process mainly by the support of government such as the Defense Advanced Research Projects Agency in the United States (Dudley, 2014). In the past ten years, the development of autonomous vehicles comes to a peak when different private and public power join the game. With more and more road tests emerging, this new transportation mode is believed to become a reality shortly (Walker, 2019; Liu, 2019; Niel, 2014).

A widely accepted standard to indicate the automation level is set out by the Society of Automotive Engineers in 2014 (Shuttleworth, 2019):

Fig. 2.2: J3016 Levels of Automated Driving (Refer to appendix 2).
Source: SAE International.

Review and Analysis of Mainstream Systems

After comparing the most advanced and well-known autonomous or semi-autonomous vehicles, several key features can be identified:

Firstly, most companies expect the application of AVs can be achieved at the beginning of the 2020s. In Singapore, where has introduced the world's first self-driving taxi service (Maxwell, 2016), the secretary of the Ministry of Transportation Peng (2017) indicates the AVs will be applied in Singapore in the next ten to fifteen years when this technology becomes feasible.

Secondly, most autonomous vehicles now belong to level 2 to level 4 according to the criteria of SAE. Actually, it is widely believed that in the near future level 5 autonomous vehicles will not appear. As Waymo's CEO Krafcik (2019) argues, autonomy will always have limitations, and the level 5 autonomous vehicle without any control from man may never exist. Hence, human drivers and AVs are going to coexist on roads in future. On the other hand, there will be a period that traditional vehicles coexist with AVs since it takes time to make self-driving cars universal (Marx, 2019).

Thirdly, those systems are predominantly tested on electric or hybrid power cars rather than petrol ones. Therefore, the supply of consistent and clean energy is one of the critical missions of urban infrastructure (Mitchell et al., 2010)

Finally, some of the participants, such as Waymo, Zoox, Uber and Baidu, are not conventional car manufacturers since passengers and mobility services will become the centre in future (Fishman, 2014).

System	SAE Level	Kilometers per Disengagement	Power Source	Application Condition
Waymo	Level 4	17,856.8	Electric Mainly	Over 5 millon road miles test completed. Formal service was launched at the end of 2018
BMW	Level 4	7.3	Electric	2021 is the estimated time of autonomy
...	...	...	...	...

Table 2.1: Comparison of mainstream autonomous vehicles
(Refer to appendix 3 for full comparison)
Information Source: State of California, et al.

Changes on Streets

By reviewing relevant literature, it is believed that the following eight changes will appear on streets following the advent of AVs:

Dynamic Kerbs

The National Association of City Transportation Officials (NACTO, 2017) believes the further potential of kerbside can be activated by dynamic pricing systems and visualising inventory. It also depicts a prospect which delivery, dining, retails and resting are fused in kerbside by reasonable management. To make dynamic kerbs more accessible, Ng (2019) suggests to remove raised concrete kerbs and use LED-embedded pavement to indicate different functions and designated area in different slots.

Charging Facilities

The transformation of power brings unprecedented demand for electricity. Mitchell, Borroni-Bird and Burns (2010) reveal six charging modes for electric-powered vehicles: domestic slow charging, quick recharge stations, exchange discharged batteries swapping stations, inductive charging pads on kerbside, embedded charging coil lines and Witricity (a system allowing longer distance inductive charging through the air). As the authors argue, the first two conductive ways and inductive charging pads are more feasible modes in the near future.

Drop-off and Pick-up Areas

The future drop-off and pick-up modes are different from today (Mitchell et al., 2010). The passengers will board or get off vehicles mainly on kerbside rather than parking lots since AVs are capable to locate passengers then bring them to destinations based on real-time traffic condition. Some scholars like Peter Colijn (2015) are working on intelligent pick-up and destination integration scheme for ride-sharing route planning. All those changes require a redesign of existing drop-off and pick-up areas.

Parking Areas

Smaller footprints of AVs, intelligent parking guiding and employment of mobility-on-demand services are three factors that reduce the demand of parking area in cities (Mitchell et al., 2010). Gruel and Stanford (2016) demonstrate that the number of private cars will decline due to the promotion of traffic efficiency and higher usage rate of single vehicles, which also help to reduce parking areas. Those spaces released from parking bring opportunities to develop new urban functions.

Intelligent Intersections

Around 40 per cent of crashes happen at intersections (Federal Highway Administration, 2009) and near one-fifth of total time on roads is spent at intersections (Brookes, 2019), but this problem is expected to be solved by AVs. Ng (2017) believes intersections in future will be more intelligent and agile to reduce waiting time. The Jaguar Land Rover is testing a technology for autonomously choosing the best route and avoiding congestion by analysing traffic information from smart intersections (Bennett, 2019). High efficient intersections are indispensable elements to satisfy growing traffic demand with less car lanes.

On-road Sensors

Real-time information plays an essential role in the future transportation system (Fishman, 2014), while ubiquitous sensors on roads are the foundation. The data from sensors provides a reference for route selection of AVs, dynamic pricing mechanism, real-time monitoring and long-term transportation planning, which all contribute to provide better mobility experience for human in future (Ng, 2017).

Longer Gaps between Fleets

Connected AVs can create much more steady and continuous traffic flow with longer distances between vehicle fleets (NACTO, 2017). Therefore, more crossing opportunities are expected to appear in future, which helps to build more walk-able and safer streets.

Dedicated Lanes

Although dedicated lanes for AVs can promote the efficiency, wider configuration of them is neither economical nor suitable for building human-centred streets since they occupy extra road space and are only affective while in medium AVs penetration rates (Ye and Yamamoto, 2018).

Automated Mass Transit

Review and Analysis of Mainstream Systems

Automated mass transit has a long history and plays a crucial role in the urban mobility system. The first automatic public transportation system is Victoria Line in London opened in1968 (Brian,2002), and now 53 fully automated metro or tram lines are distributed in 36 cities (Wilkins, 2016). Some of them such as Barcelona Metro line 9 and Copenhagen line 1 have already reached Grade-of-Automation 4 (GoA4) degree, which means fully automated operation is available and human drivers are unnecessary on vehicles (IEC, 2014). It is estimated that over 2,200 km of automated metro lines will be operated in the world by 2023 (Wilkins, 2016). As for automated buses, Volvo and Nanyang Technological University are testing the world's first fully autonomous bus in Singapore, and it is expected to serve commuters by 2022 (Wei, 2019). There are also delivered automated buses operated in small scale site such as Mcity Driverless Shuttle Bus in the University of Michigan.

Some common features of automated mass transit can be found from literature and practical examples. The CityMobil2 project (CORDIS, 2016) reveals that automaton or autonomy relies on GPS, cameras, radars and obstacle-avoidance technology. Wilkins (2016) argues that mutual communication among vehicles, stops and transportation control centre is another key aspect to achieve automation. Another feature of new buses refers to the size of vehicles. For example, the automated buses from Volvo and Mercedes Benz have similar shapes with conventional buses, while most of the others are featuring smaller size and more agile operation such as WEpod, EasyMile EZ10, Olli and Navly (e.g., IEEE, 2016).

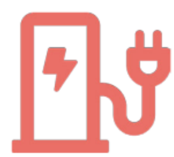
In terms of advantages, automated mass transit can promote safety, reliability and flexibility of traffic system significantly while compared with conventional public transport (Wilkins, 2016).

Changes on Streets

There are four changes from automated mass transit:

Intelligent Platforms or Stops

More information including bus arrival time, vacancies on board, traffic condition and local guidance will be presented by the support of display devices and internet connection on platforms and stops (e.g., Geetha and Cicilia, 2017).



Charging Facilities

Similar to AVs, automated mass transit is mainly electric-powered (Mitchell et al., 2010). Terminal station recharging is more reasonable for public transport and prototype of inductive charging strip on road surface demonstrated by KAIST (2009) can be another solution in future.

Drop-off and Pick-up Area

Smaller footprints of automated mass transit and new street facilities around stops both require redesign of drop-off and pick-up areas.

Shorter Headway

Connectivity among vehicles brings shorter headway with no promise on safety and connotes more frequent buses or metros during peak hours (NACTO, 2017).

Shared Bicycle and E-scooters

Review and Analysis of Mainstream Systems

The earliest shared bicycle was introduced in Amsterdam in 1965 (Shaheen et al., 2010) and the latest generation of shared bicycles which feature large-scale covering, electronic locker, mobile payment and real-time information dates back to the programme called Velib in Paris with instant success in 2007 (Collinson, 2017). According to the report from Roland Berger (2018), there are around 1,250 bike sharing systems operated in 71 countries in 2017 and China is the biggest market with over 2.35 million bikes deployed.

Docking station shared bicycles, and dock-less shared bicycles or e-scooters are two mainstream categories of shared bicycle service. Those two systems have different spatial features since the first relies on fixed docks on streets for renting and returning, and another one can be rent and returned more freely (Shaheen et al., 2010). In the past few years, electric bikes and scooters appear and become another form of shared vehicles, and they can be operated in either way above.

The spreading deployment of shared bicycles in cities can encourage the usage of bicycle and facilitate the “last miles” commuting experience (Paul, 2009). It shares the same advantages with conventional bicycles, including low pollutant emission, conducive to health, and economical (Heinen et al., 2009).

There are also challenges coming with shared bicycles and scooters. The surge of bicycles and scooters produce unprecedented pressure on transportation infrastructure, and many cities do not have adequate parking facilities for them. Another challenge is the lack of dedicated lanes, which compels cycles to share the same lane with motor vehicles. Some cities like Seattle failed to tackle the dilemma and shut down the service (Retrieved, 2017).

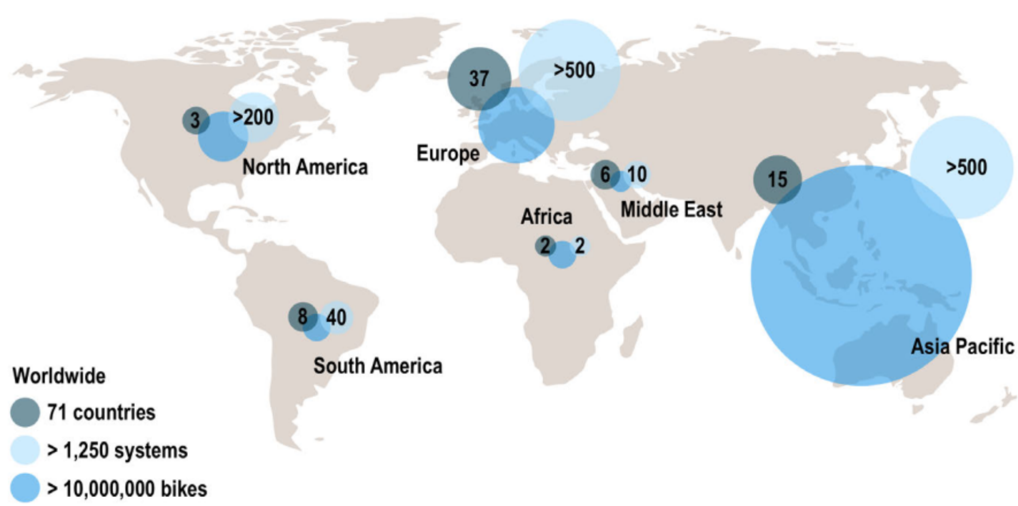


Fig. 2.3: Distribution of shared bicycle system in the world
Source: Roland Berger, 2018

Changes on Streets

Shared bicycles and e-scooters require following corresponding changes to maximise their efficiency:

Dedicated Lanes

Dedicated lanes with physical separation have a positive impact on promoting cycle safety, efficiency and comfort (e.g., Liu et al., 2012). Distinguishable painted surface, vertical barriers and elevated lanes are common ways to demarcate bicycles and other motorised vehicles (peopleforbikes, 2014).

How to configure cycle lanes in urban areas is another factor affecting user experience. Alrutz et al. (2012) demonstrate that deploying two-way cycle lanes on one-way streets can increase accessibility to residential areas and avoid arterial streets for cyclists.

Parking Areas

Dock-less mode is regarded as the trend in future (Roland Berger, 2018), and it requires more flexible and diverse parking plots. Parking management is a crucial issue to cope with the spreading deployment of shared small vehicles in larger city scales (Spek and Scheltema, 2015). Moreover, geofencing technologies have been used in some practical programmes such as Urbee and Mobike to regulate specific parking areas by restricting pick-up and unlock while using the application on smartphones (Waes et al., 2018).

Cycle-friendly Facilities

Dedicated street facilities are key vital components to promote cycle experience and encourage usage of bicycle. (Roland Berger, 2018). Designated waiting area at a signalised intersection, detectable bicycle traffic signals, bicycle lift, oblique trash cans and road condition indicators are proved to be conducive to cycling (e.g. Clark and Page, 2000).

Charging Facilities

Charging facilities are necessary for electric bicycles and scooters since the battery capacity of these vehicles is insufficient for full-day operation (Christopher et al., 2010). Christopher et al. (2010) also indicate that battery charging and photovoltaic solar panels are two key components at electric bicycle stations. As for dock-free mode, the e-scooter programme Bird appeals to their users to recharge those e-scooters at home with a payment of 5 to 20 dollars per scooter per charge (Yakowicz, 2019).

Better Delivery System

Mainstream System Review and Analysis

Freight and delivery are essential activities in urban transportation (Crainic et al., 2004). With the rapid development of electronic commerce and food delivery service, the demand for delivery in cities surges in the past decade (Morganti et al., 2014). China has a total e-commerce transaction value of 31.63 trillion in 2018, and over 5 billion parcels were delivered to customers (Zhao, 2018).

To cope with the huge amount of delivery, pick-up points in stores and automated lockers networks are introduced (Morganti et al., 2014). DHL Packstation service launched in 2001 is regarded as the pilot in this field. Similar service has spread in many metropolia such as ParcelMotel in the Republic of Ireland, SmartPOST in Finland, Døgnpost in Denmark and Fengchao in China. They are usually deployed in shopping centres, stores or other public domains. Take the Amazon Locker as an example, it partners with convenient stores such as 7-Eleven in the US (Chao, 2015) and Co-operative Food and Morrisons in the UK (Campbell, 2012).

Goodchild and Ivanov (2017) argue that the final 50 feet is a segment of the whole delivering online purchases and they believe city department of transportation is the key role to control kerb space, streets, alleys and sidewalks where trucks load or unload cargo and purchasers collect their goods.

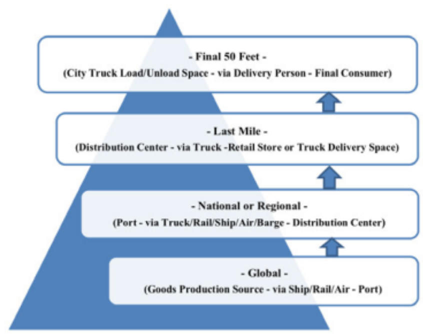


Fig. 2.4: Supply Chain Segments.
Source: Goodchild and Ivanov, 2017.

Changes on Streets

For better final delivery, streets should provide following elements:

Delivery Lockers

It is be proved that delivery locker can elevate the success rate of the first delivery attempts and reduce the fragmentation of final deliveries. Also, their deployment can decrease congestion and pollution due to freight activities (Morganti et al., 2014).

Loading and Unloading Area

Managed and bookable loading and unloading area is important for freight in urban areas since it can reduce delivery time by assisting drivers to approach their desirable loading area efficiently (McLeod and Cherrett, 2011).

Dispatch Station on Streets

Through a practical test of light electrical vehicles used for last-mile delivery in European seven cities, it is demonstrated that dispatch systems on streets have great benefits on business cost, environment and transportation (Lia et al., 2014).

Case Studies - Changes on Streets

Fig. 2.5: Tesla's quick charge station.
Source: Freightwaves, 2019.

Fig. 2.6: Dedicated pick-up area for Uber and Lyft in Las Vagas.
Source: Thepointsguy, 2016.

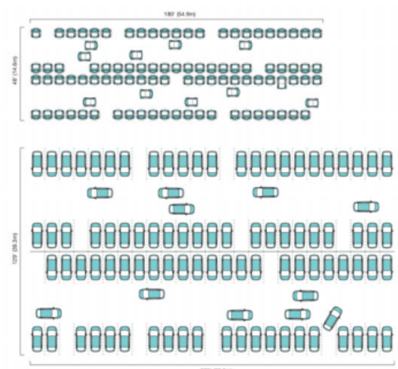


Fig. 2.7:
Parking area comparison between AVs and normal cars.
Source: Mitchell et al., 2010.

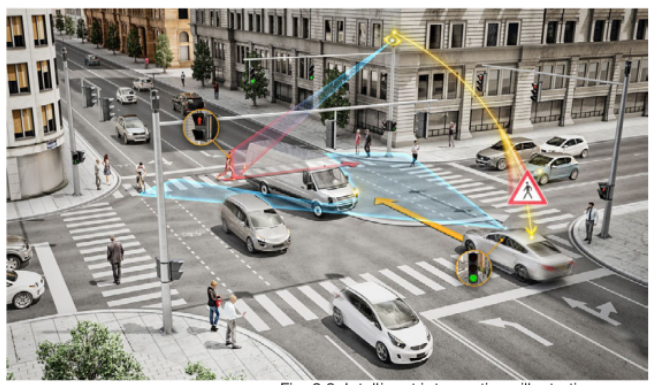


Fig. 2.8: Intelligent intersections illustration
Source: Smartcitiesworld, 2017.

Fig. 2.9: Momentum's 200 kW wireless charging system in Wenatchee.
Source: Ridden, 2018.

Fig. 2.10: Shandong Kaich Intelligent bus stop in Shandong.
Source: Kaichsmartcity, 2018.

Case Studies - Changes on Streets

Fig. 2.11: Well equipped cycle lane in Manchester.
Source: David Edgar, 2017.

Fig. 2.12: Dockless shared bicycle parking plot in Singapore.
Source: Land Transport Authority, 2018.

Fig. 2.13: Shared bicycle docking station in London.
Source: Stanford, 2012.

Fig. 2.14: Trash can for cyclists in Copenhagen.
Source: Acharya, 2017.

Fig. 2.16: Daymak wireless E-Bike charging stations.
Source: Teal, 2017.

Fig. 2.15: Delivery lock beside a tube station in the UK.
Source: Inpost, 2017.

Fig. 2.17: Delivery lock beside 7-Eleven.
Source: Vega, 2017.

Case Study - Quayside in Toronto

This is an urban regeneration project on 4.9 hectares (12 acres) of land in south Toronto developed by Waterfront Toronto and planned by Sidewalk Labs.

One of the key topics in this project is the smart city and intelligent transportation system. Different traffic modes and corresponding facilities including trams, buses, shared bicycles, e-scooters, dynamic kerbside and automated delivery system are discussed in this project. Therefore, it is a suitable reference for studying how intelligent technologies are integrated and coordinate in one place.

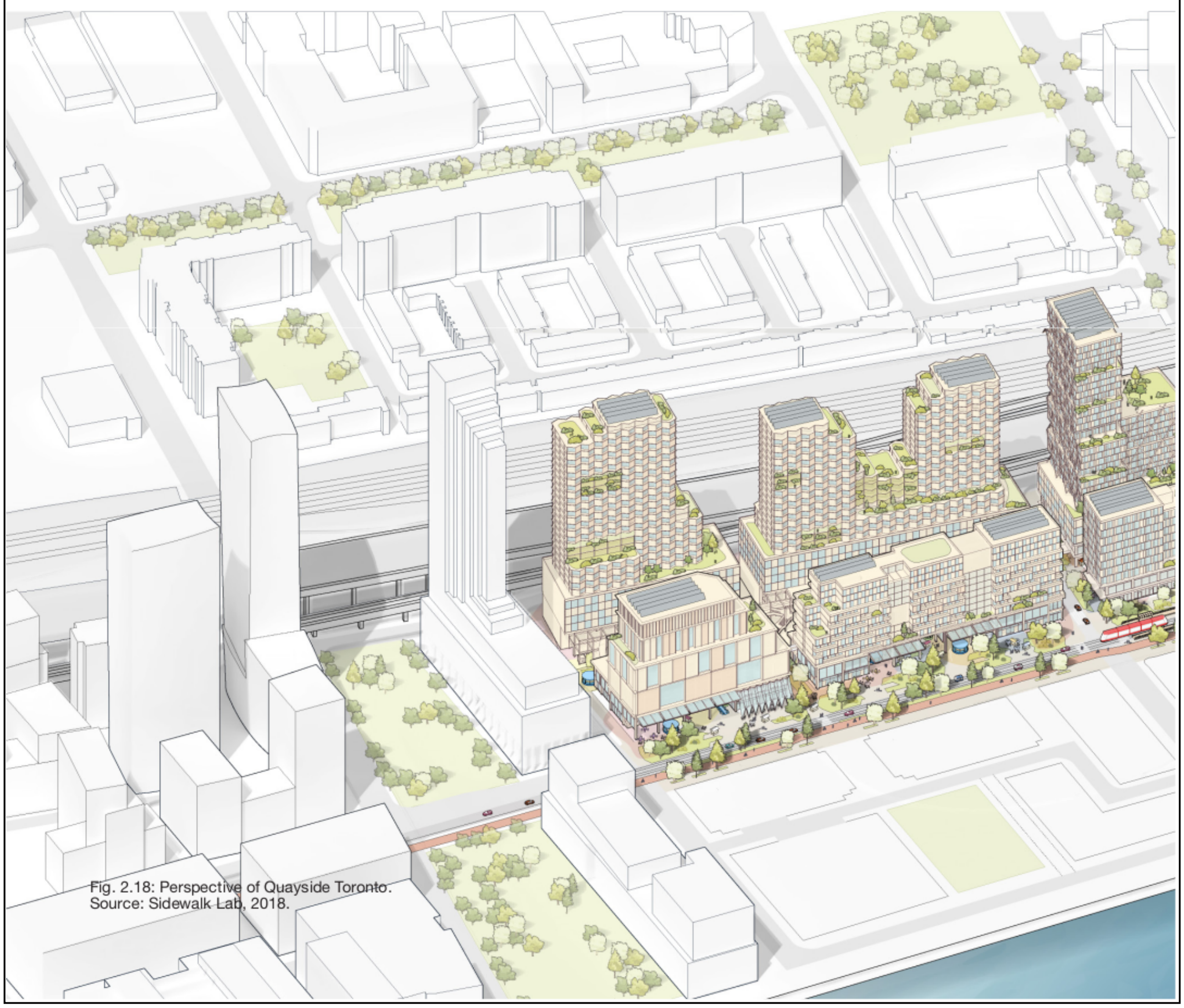
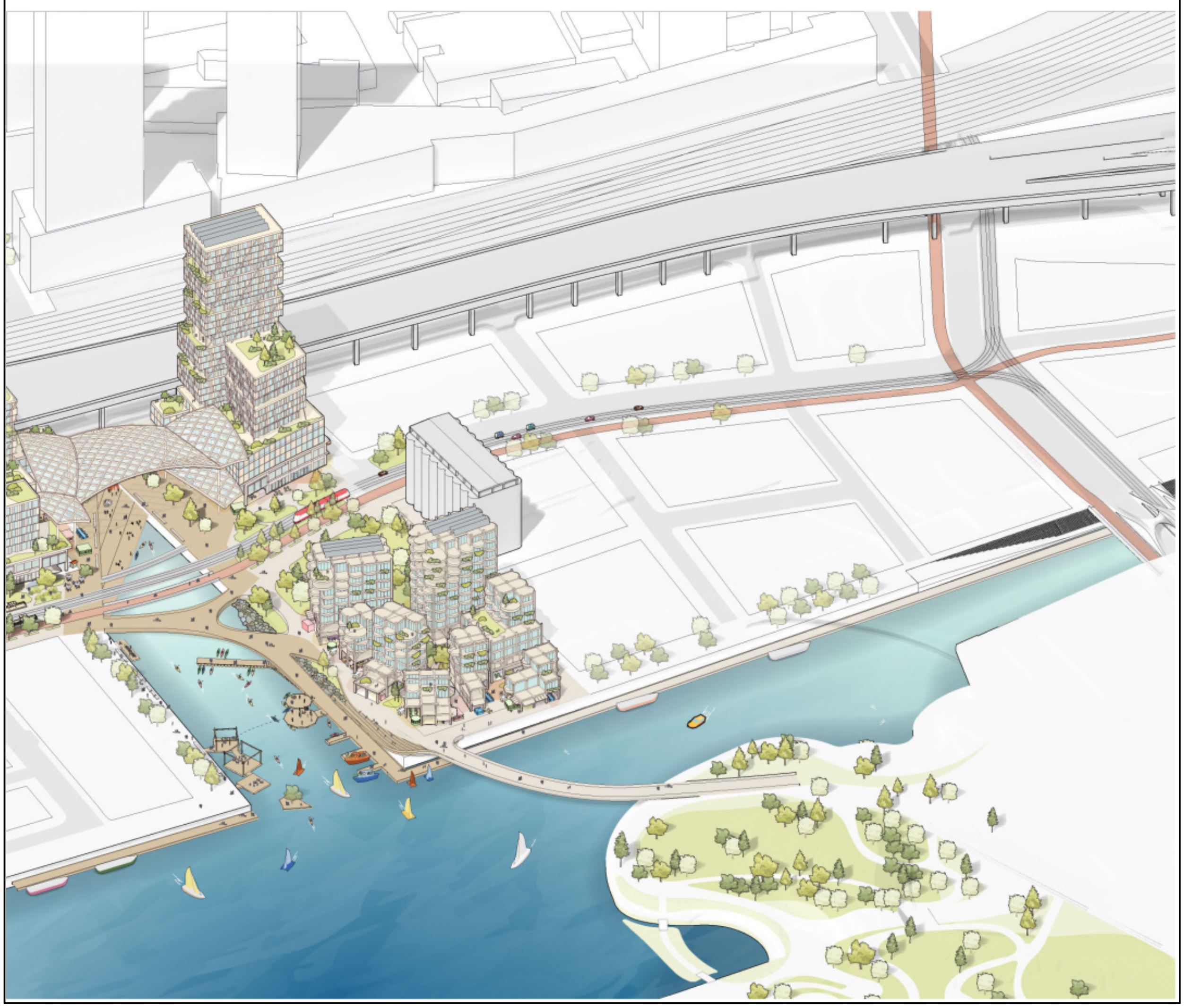


Fig. 2.18: Perspective of Quayside Toronto.
Source: Sidewalk Lab, 2018.

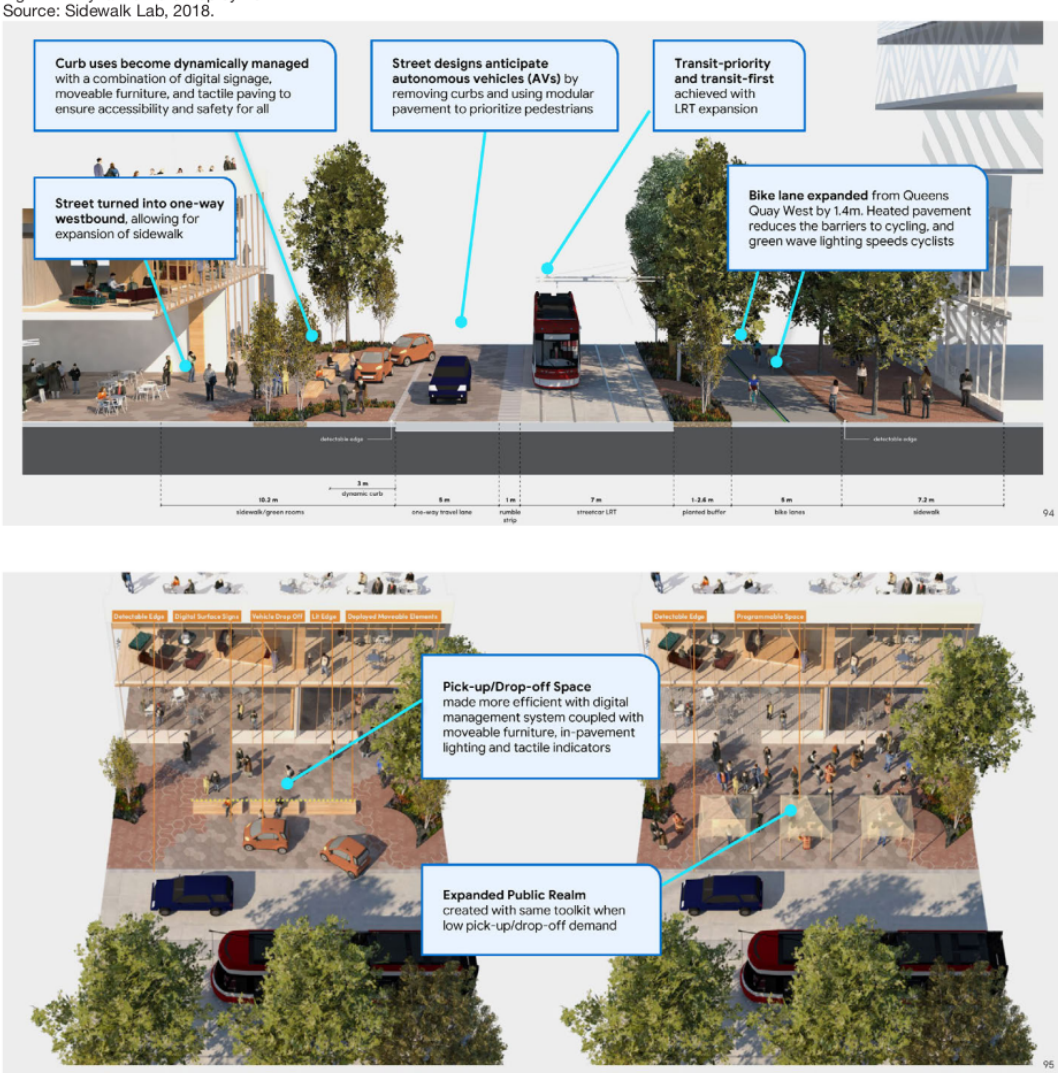
Fig. 2.19: Accessibility Map of the Site.
Source: Sidewalk Lab, 2018.



Findings of Kerbside Usage

- Conventional elevated kerbs are removed so that pedestrians, passengers and stalls can access more easily.
- Digital and dynamic management enable multifunctional kerbside at different time, which transforms kerbside to extensible public realms and blurs the edge between pavement and vehicle lanes.
- Movable furniture and in-pavement indicators are crucial components to achieve flexible street configuration.

Fig. 2.21: Dynamic Kerb Deployment.
Source: Sidewalk Lab, 2018.



Findings of Bicycle and E-scooter

- Parking or renting area is embedded beside or within buildings to make the usage of them more convenient.
- Bicycles or e-scooters are integrated with mass transit systems (Trams and buses). By creating seamless transfers among them, the project can encourage active mobility patterns and reduce private car usage.

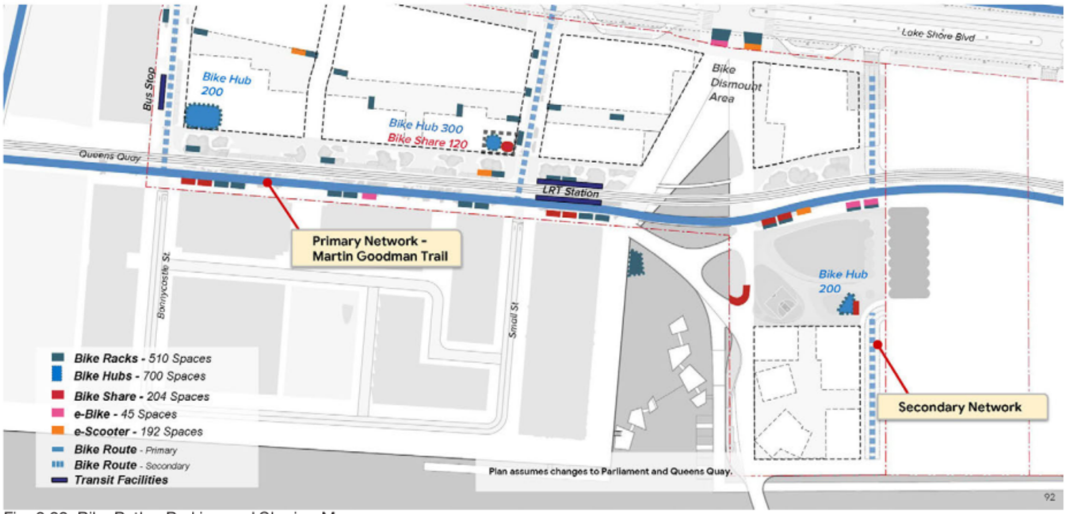


Fig. 2.22: Bike Paths, Parking and Sharing Map.
Source: Sidewalk Lab, 2018.

- Cycle routes are separated on main roads but integrated on peripheral paths. Both types of cycle routes are connected to form a complete and permeable cycle network, which promotes cycling experience and accessibility.

Fig. 2.23: Bike Network.
Source: Sidewalk Lab, 2018.

Deficiencies & Challenges

- **No charging facility**

The proposal does not mention any charging facility for AVs, electric cars and bicycles (or e-scooters), which is a fundamental element in larger sites for supporting electric-led mobility.

- **Lack of Intelligent Intersection**

Intelligent intersections can prioritise non-motorised traffic modes (NACTO, 2017). The lack of them will make it difficult to organise pedestrian flows, cyclist flows and vehicle flows with more complex circumstance.

- **Deployment of other mass transit**

Other public transport such as metro or BRT is not discussed in this project, which makes it not a useful reference for those areas without tram systems.

- **Unclear connection with wider urban area**

The connection between other areas in the city is important, but it is missing in the proposal

- **No parking and waiting areas for vehicles**

Suitable parking and waiting areas are important for larger sites since there is a large traffic volume in peak hours. The lack of those areas connotes that vehicles have to wait outside the site bringing traffic pressure to other places.

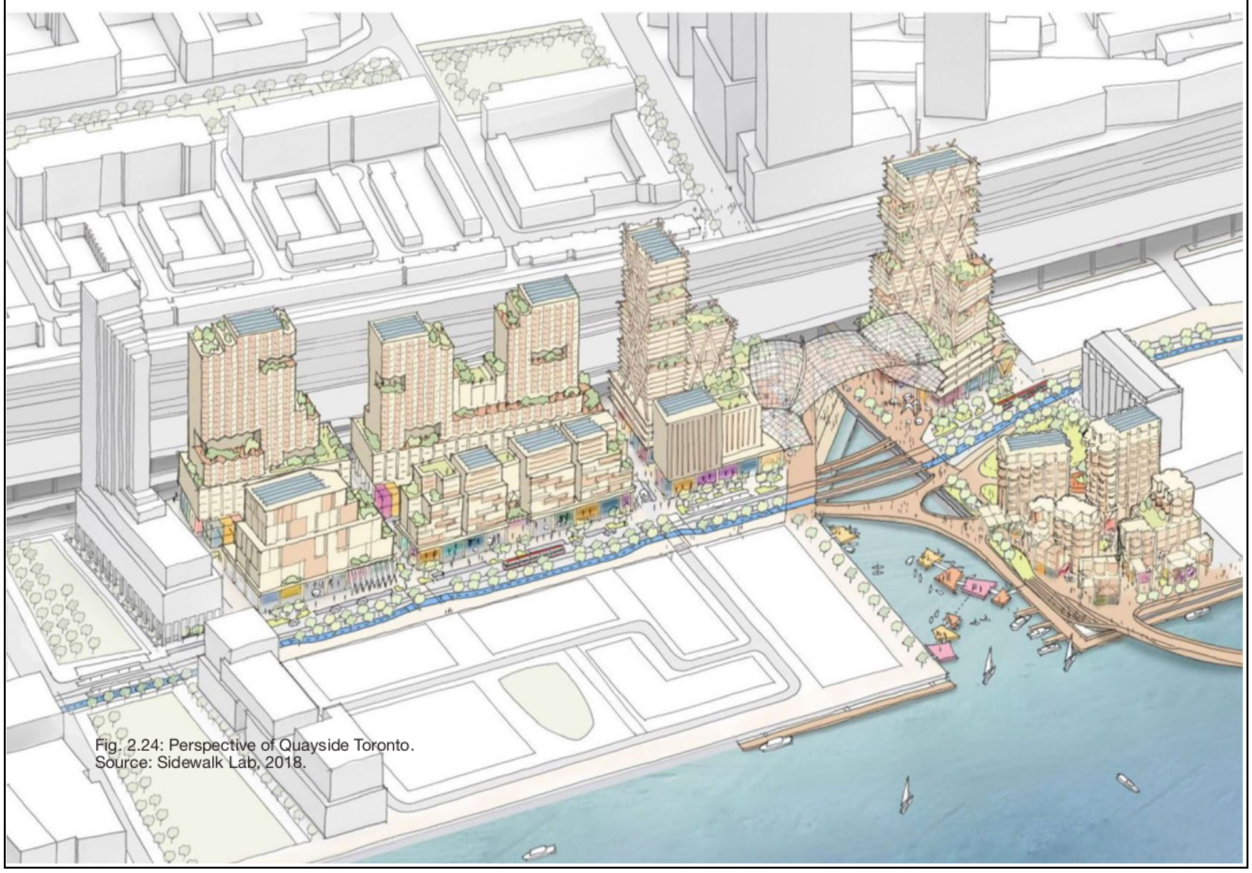


Fig. 2.24: Perspective of Quayside Toronto.
Source: Sidewalk Lab, 2018.

TOOL-KIT FORMATION

3

Tool-kit Formation

The tool-kit starts with the reviewed literature of four traffic modes to figure out the required changes. Then certain changes are integrated to form different design tools. Therefore, every tool not only reflects different changes on the streets but also responds to different traffic modes.

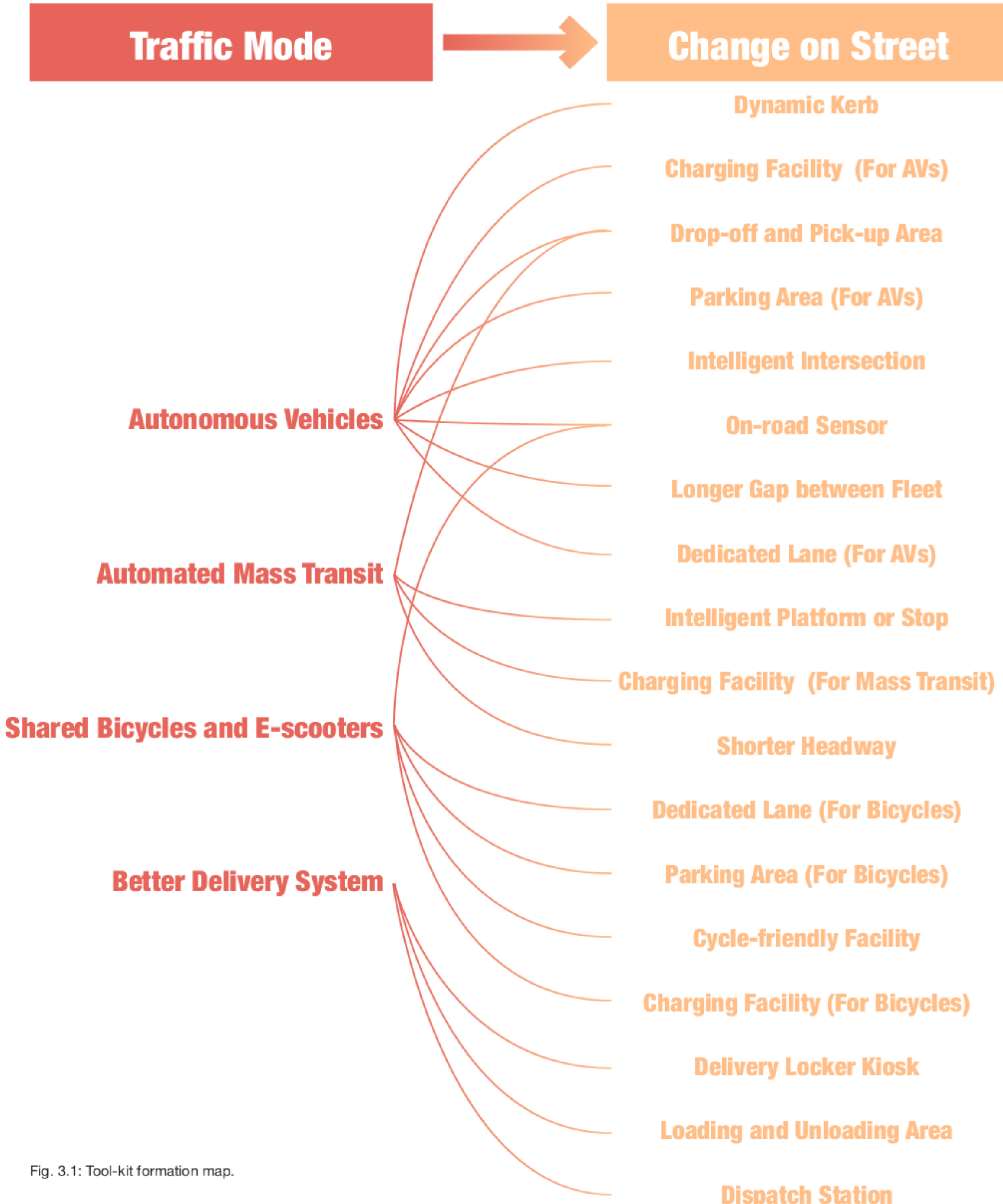
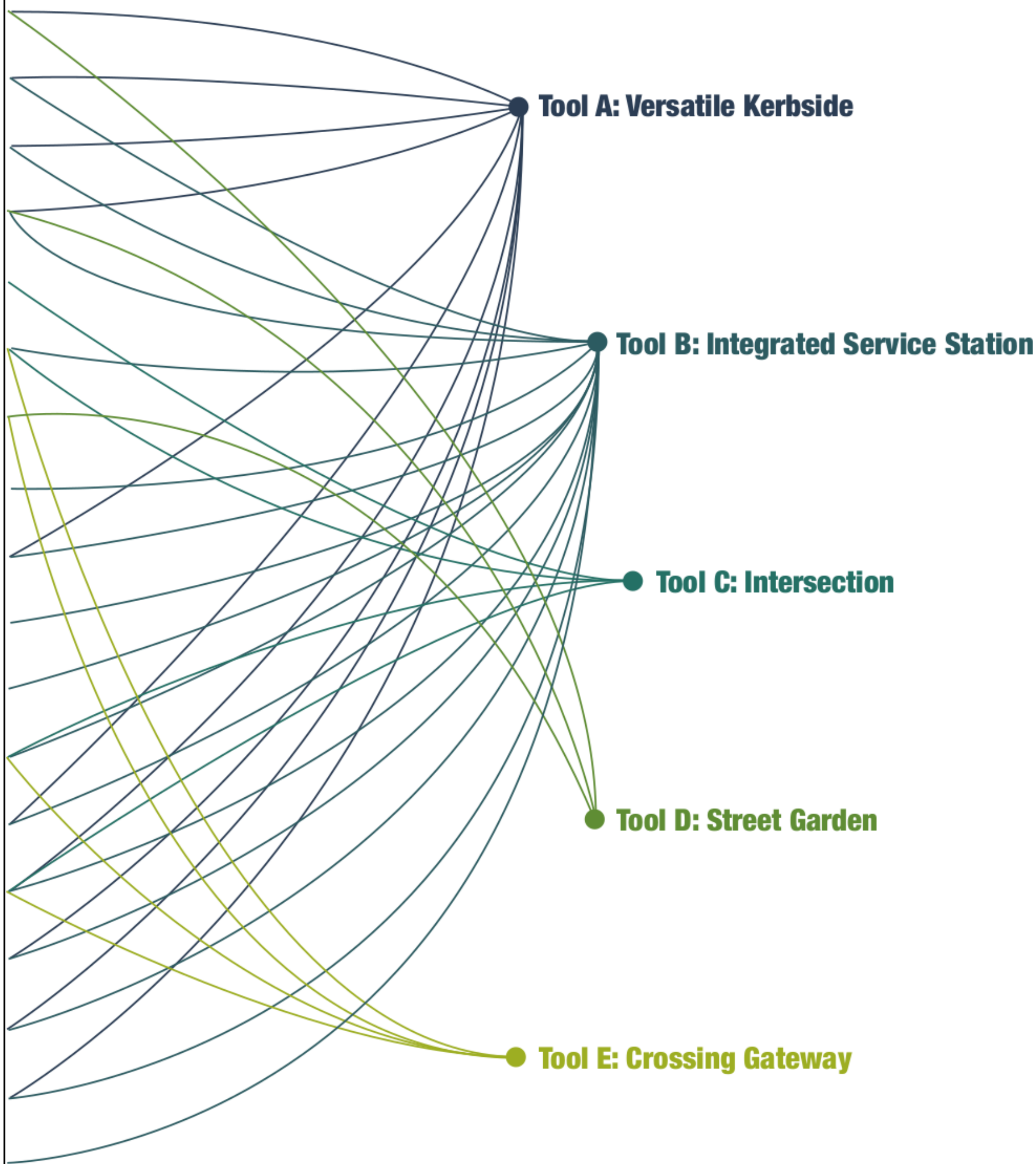


Fig. 3.1: Tool-kit formation map.

*Traffic direction is based on international rules.

Tool-kit*

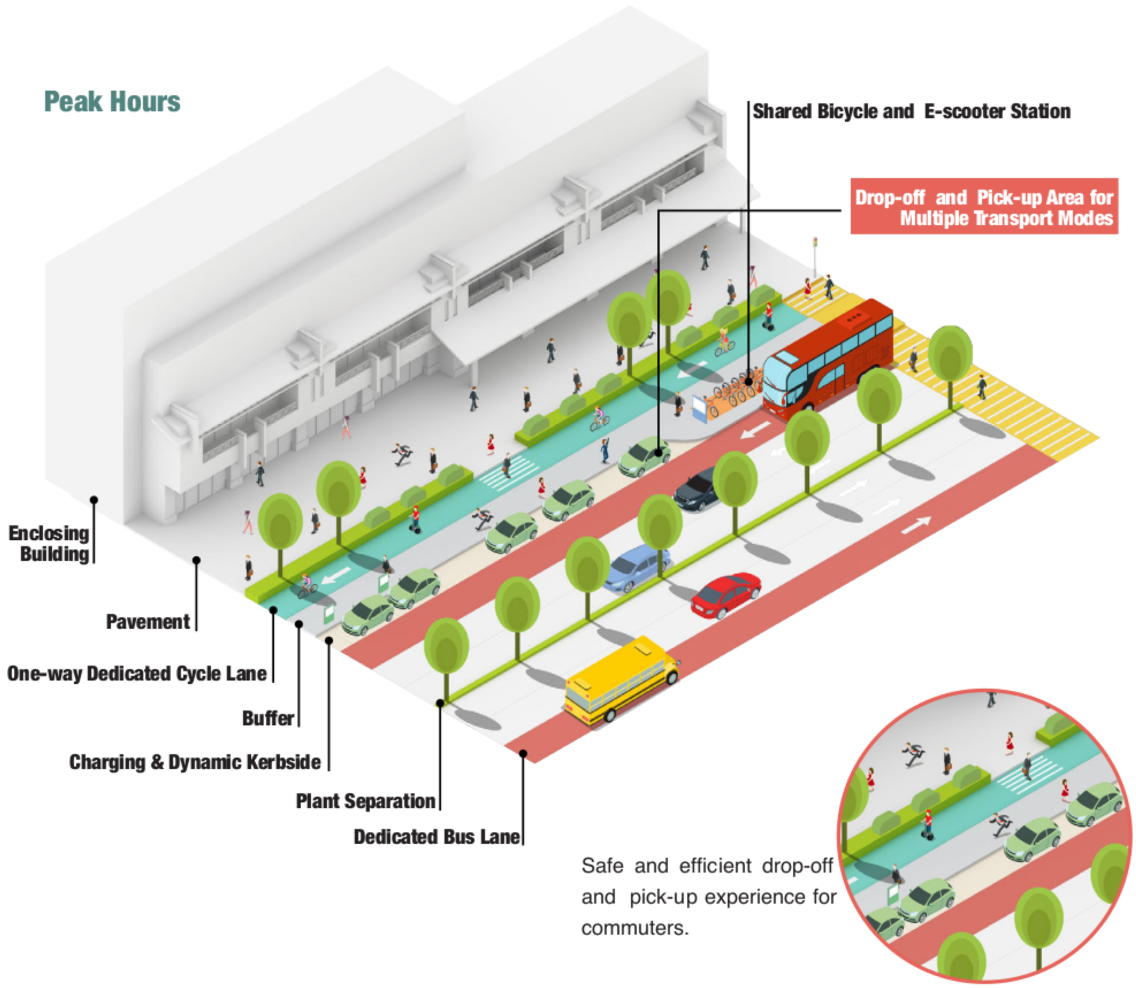


Tool A
Versatile Kerbside (With One-way Cycle Lane)

Tool A is the most vital tool to maximise the potential of streets. The overall idea is modularising the kerbside both spatially and temporally. This tool explores the possibility of more accessible public realm on streets for humans.

When the traffic efficiency and the usage rate of single vehicles are promoted by new traffic modes , streets can support the same transport volume with less car lanes and parking area. Then more spaces are released to be transformed to wider pavement, continuous cycle lane, greening, more comfortable queueing area and other urban functions for humans. On the other hand, the decrease of private cars help to build more quiet and walkable kerbside environment for people.

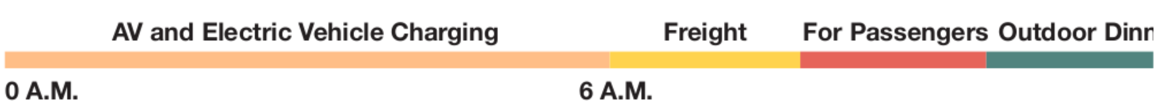
Peak Hours



Safe and efficient drop-off and pick-up experience for commuters.

Commuting

Kerbside Dynamic Management



Objective Accomplishment

From vehicle-centred to human-centred

Fig. 3.2: Versatile Kerbside (With One-way Cycle Lane).

Off-peak Hours

Food Truck and Delivery Collection

Dynamic management brings opportunities to small business and pop-up market. Food delivery and outdoor dinning can be integrated so that people can escape from tiring indoor working then enjoy their meal and gossip with each other.

Outdoor Dinning and Casual Meeting Place

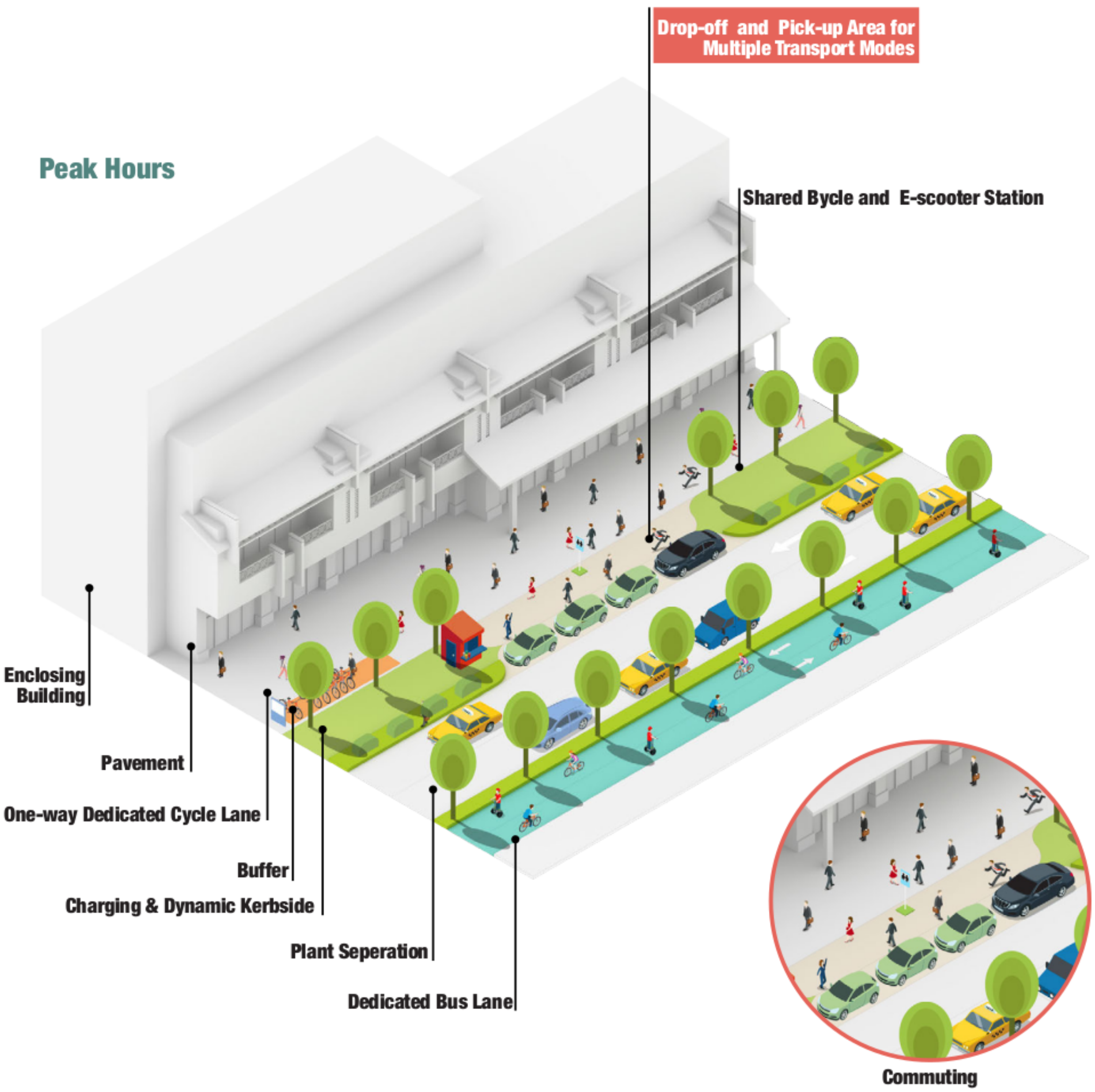
ing, Food Delivery and Other activities | **For Passengers** | **Outdoor Dinning** | **Freight**

12 P.M. | **6 P.M.** | **10 P.M.** | **12 A.M.**

Tool A
Versatile Kerbside (With Bidirectional Cycle Lane)

Here is another type of versatile kerbside with a bidirectional cycle lane on one side, which can even offer more spaces on the side without cycle lane for strip gardens.

Peak Hours



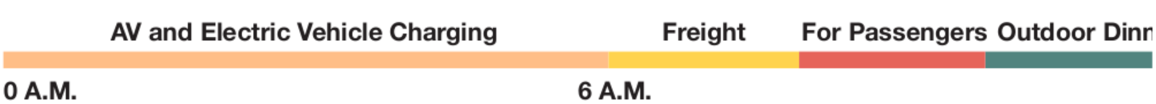
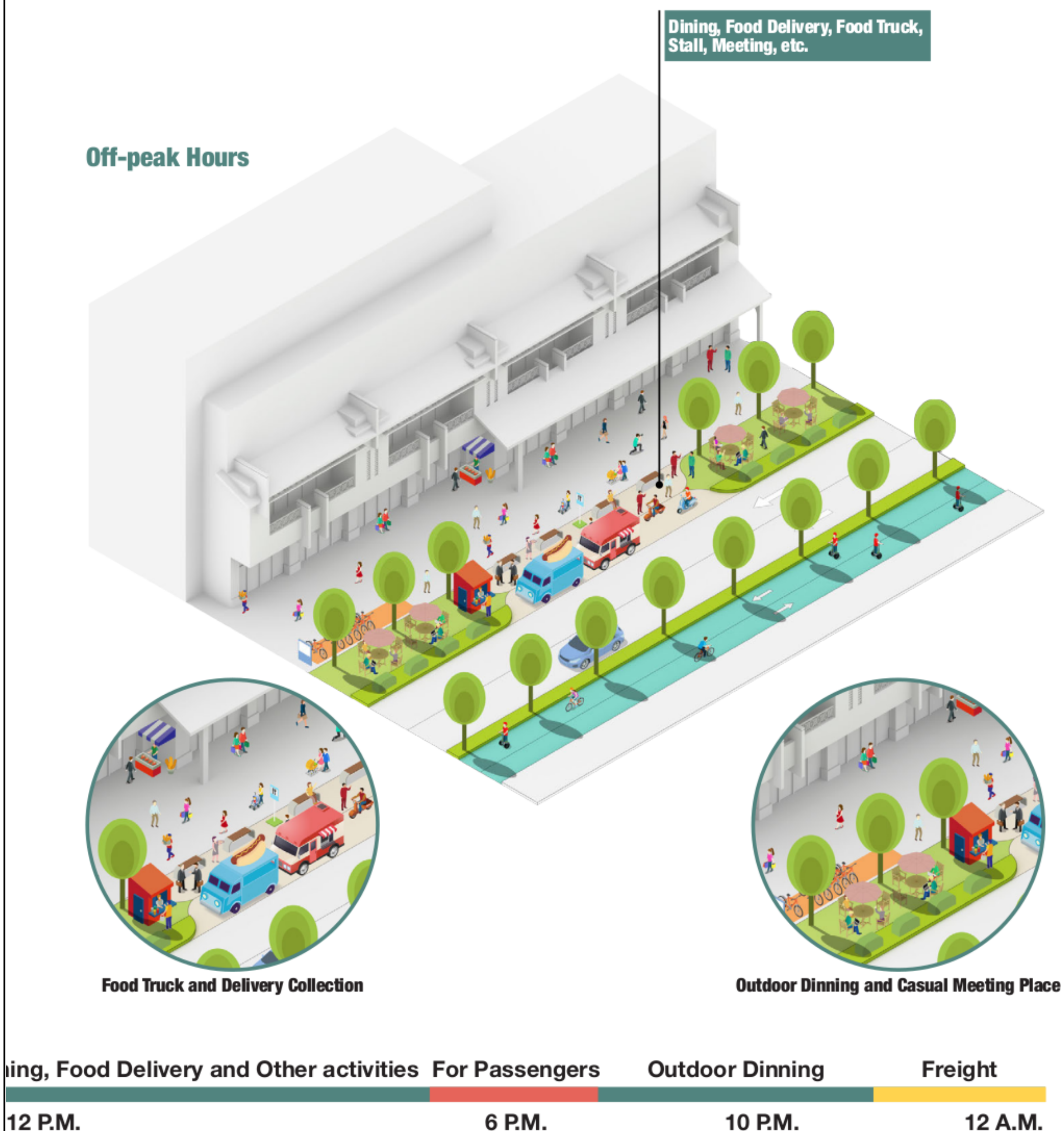
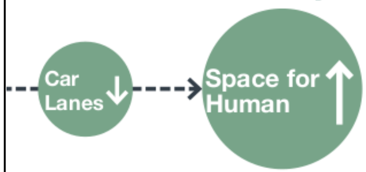


Fig. 3.3: Versatile Kerbside (With Bidirectional Cycle Lane).

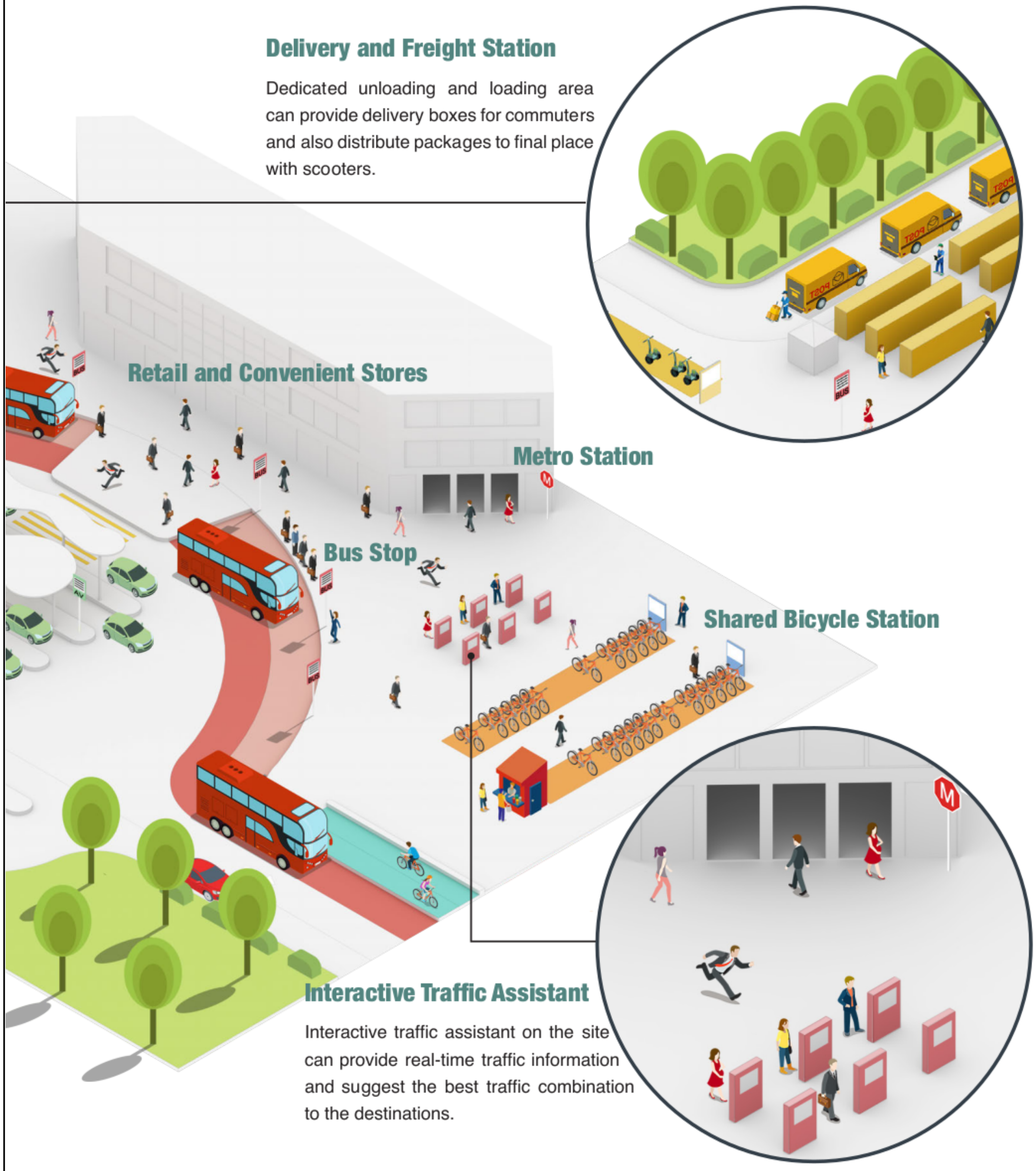


ernatives to create more space for human



Delivery and Freight Station

Dedicated unloading and loading area can provide delivery boxes for commuters and also distribute packages to final place with scooters.



Interactive Traffic Assistant

Interactive traffic assistant on the site can provide real-time traffic information and suggest the best traffic combination to the destinations.

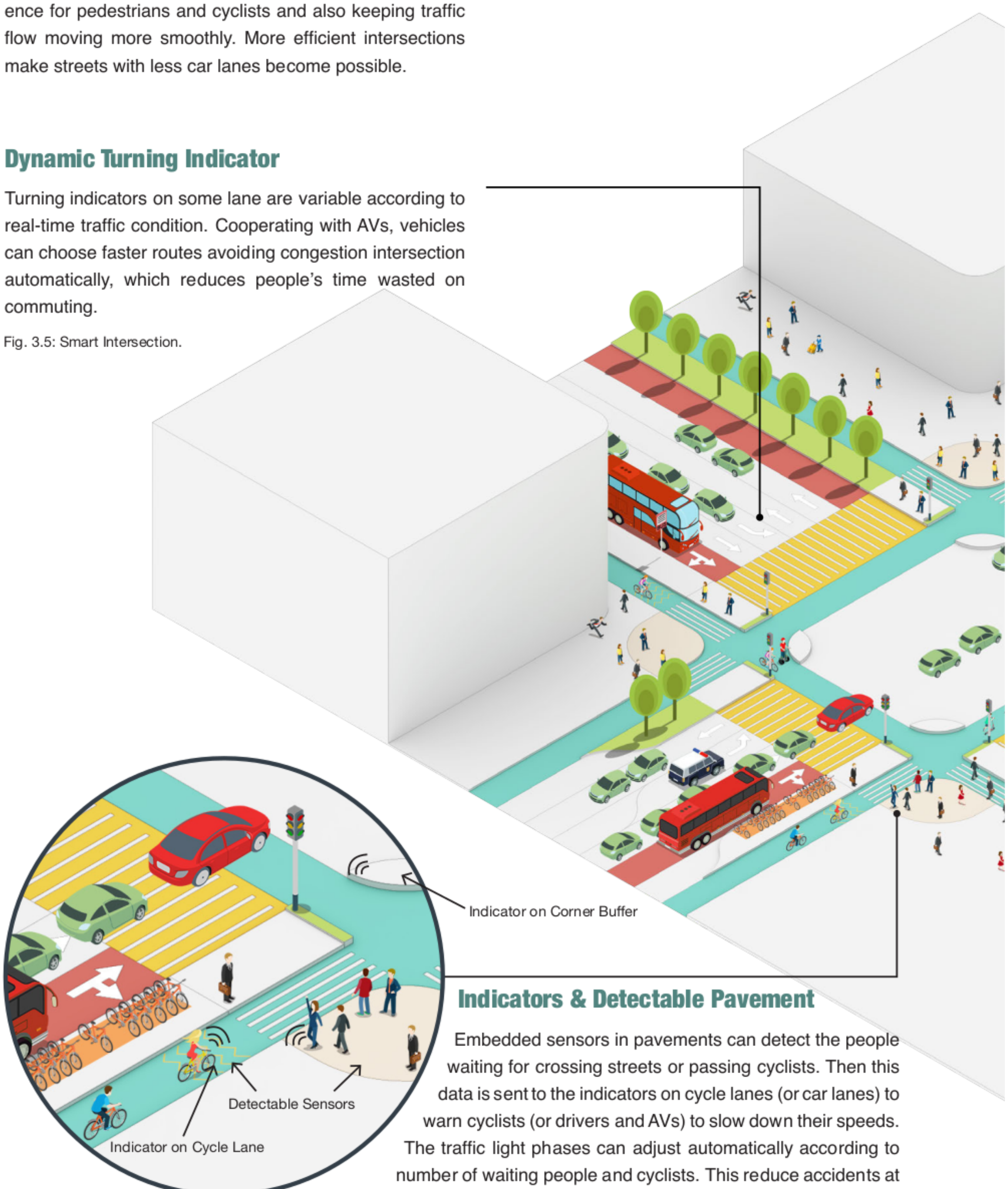
Tool C
Smart Intersection

This tool aims at providing better passing through experience for pedestrians and cyclists and also keeping traffic flow moving more smoothly. More efficient intersections make streets with less car lanes become possible.

Dynamic Turning Indicator

Turning indicators on some lane are variable according to real-time traffic condition. Cooperating with AVs, vehicles can choose faster routes avoiding congestion intersection automatically, which reduces people's time wasted on commuting.

Fig. 3.5: Smart Intersection.



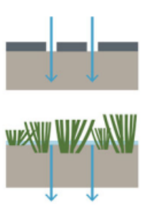
Indicators & Detectable Pavement

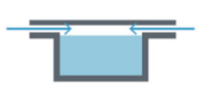
Embedded sensors in pavements can detect the people waiting for crossing streets or passing cyclists. Then this data is sent to the indicators on cycle lanes (or car lanes) to warn cyclists (or drivers and AVs) to slow down their speeds. The traffic light phases can adjust automatically according to number of waiting people and cyclists. This reduce accidents at intersections and promote safety of all kinds of people.

Tool D
Street Garden

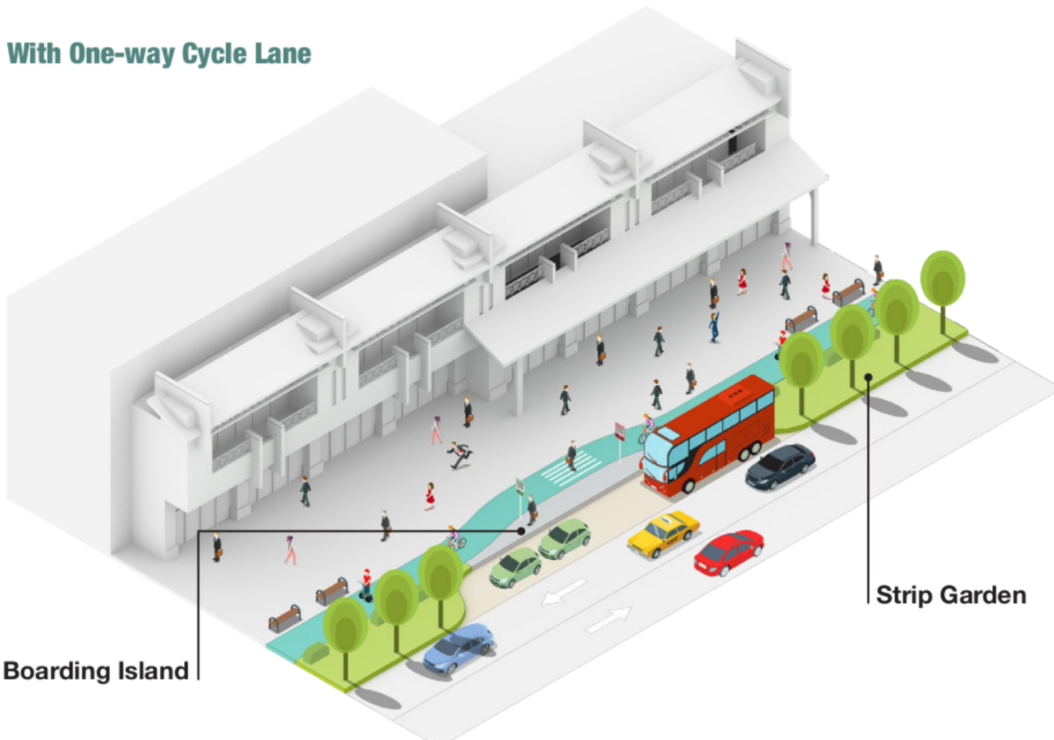
Road spaces released from side parking can be used to deploy more urban greening. Those generated green patches can designed as leisure space, educational gardens, healing gardens and even city farms

With Bidirectional Cycle Lane





With One-way Cycle Lane



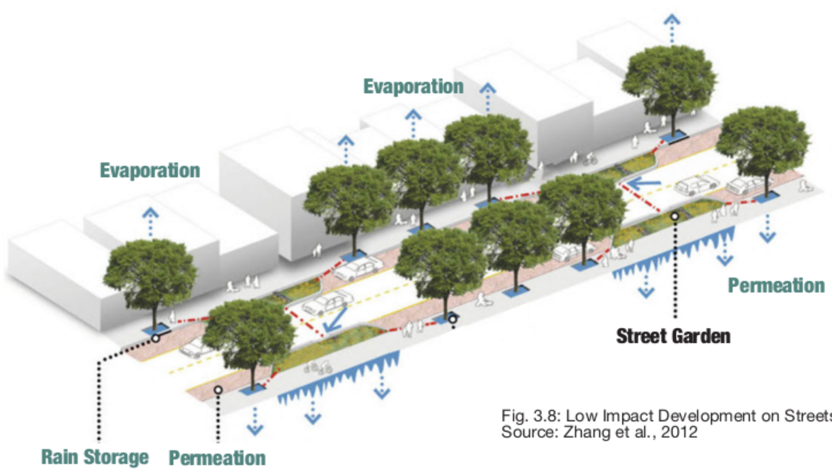
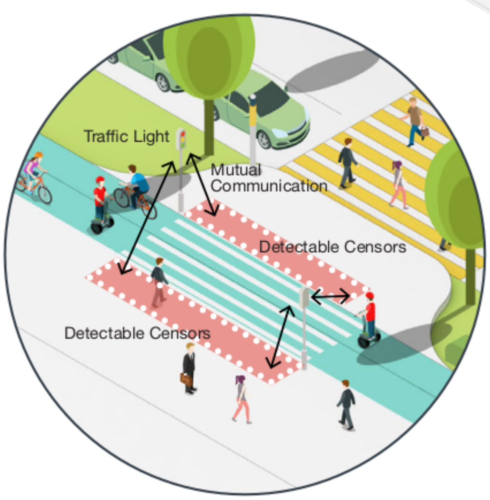


Fig. 3.8: Low Impact Development on Streets
Source: Zhang et al., 2012

Tool E
Crossing Gateway

This tool is derived from an intrinsic feature of longer gaps between autonomous vehicle fleets. It brings the opportunity of more frequent crossing on our streets.

Fig. 3.9: Crossing Gateway.



Cyclists and Pedestrians

Sensors and indicators also coordinate to reduce conflict between cyclists and pedestrians by intelligent traffic lights on cycle lanes.

Safer Crossing

The embedded sensor in gateways can detect the coming pedestrians and tell nearby AV fleet that someone is going to cross the street so that fleets can slow down before they approach the crossing gateway.

Tool-kit Benefit Assessment Matrix

How do people benefit from different tools?

Vibrant and Versatile Public Realm

Transformed kerbside becomes vibrant and versatile urban public space for different kinds of people and revives street life.

This tool provides services beyond transportation such as retail stores, pocket garden and delivery collection for people.

Strip gardens alongside roads create widely-distributed space for people to have various activities. Trees provide shade and also decrease noise from roads.

Crossing Gateway can encourage walking and strolling on street which stimulates the retail footage and brings vibrancy to adjacent commercial facilities.

Table. 3.1: Tool-kit benefit assessment matrix.

 Safe and Resilient Street	 Integrated Transport Network
This tool builds safer streets for people by allocating dedicated transport space and narrowing down motor lanes. Street resilience is also promoted by increased green land alongside roads.	This tool provides flexible space to support multiple traffic modes right beside the pavement, and well-organised cycle lanes promote active mobility experience.
Ordered pedestrian and vehicle flows promote street safety.	This tool contributes to creating more integrated transport experiences and simplifying commuters' daily traffic transfers.
Majority of traffic accidents occur at the moment of turning and crossing. Dedicated cycle lane and pavement with protective buffer and embedded sensors can promote street safety and reduce fatality significantly.	The left turn pocket can leave the lane for vehicles going straight. Queue jumping lane for buses is demonstrated to promote efficiency of public transport (NACTO, 2017)
The crucial contribution of this tool is promoting city resilience by increasing green coverage ratio in dense urban area and help to create a more pedestrian-friendly environment.	Street gardens help to build a more walkable city that not just for private cars but multiple traffic modes.
Shorter cross distance and coordination between AVs and infrastructure can promote street safety significantly.	More frequent crossing opportunities can reduce detour distance for pedestrians and enhance the active mobility network.

METHODOLOGY

4

Methodology

The research question and research gap are put forward at the beginning. A brief research background referring to the significance of the new generation transportation reveals the immense potential of intelligent technologies for tackling traffic problems and making better streets. After that, research objectives are set out to conduct the whole investigation. By reviewing deficiencies of the existing infrastructure and global regulatory environment, the research problem is put forward. The main research methods in this stage are library research and field research.

After comparing development level, possibility in the near future and application condition of different technologies, the literature review focuses on four mainstream innovative transportation modes: autonomous vehicles, automated mass transit, shared bicycles and scooters, and better delivery system. Transportation policy documents, laws, government work reports, academic dissertations and books are the studied documents.

Through literature, corresponding changes on streets from different transportation modes are found and become the foundation of tool-kit. Different precedents and a comprehensive case in Toronto, which has significant progress on testing, applying, operating and managing the similar transportation systems, are reviewed as reference for both tool-kit formation and later proposal.

In tool-kit section, different changes on streets are integrated into five tools containing the deployment of four discussed traffic modes. Explicit description of different tools is showed with axonometric drawings and the benefits for people and cities from the tool-kit is discussed to ensure all tools are following the set-out research objectives.

The applications section starts with the existing situation of the site, followed by the discussion about why it is not a human-centred place now. To better understand the traffic problems, interview of local commuters and data investigation are also utilised in this section. Strategies based on set-out tool-kit are put forward to transformed those single-function traffic spaces to more human-centred places. Space syntax is also used to justify the chosen street for strategy application. Since the tool-kit covers different types of space such as roads, intersections and stations, the proposed strategies can be considerably practical.

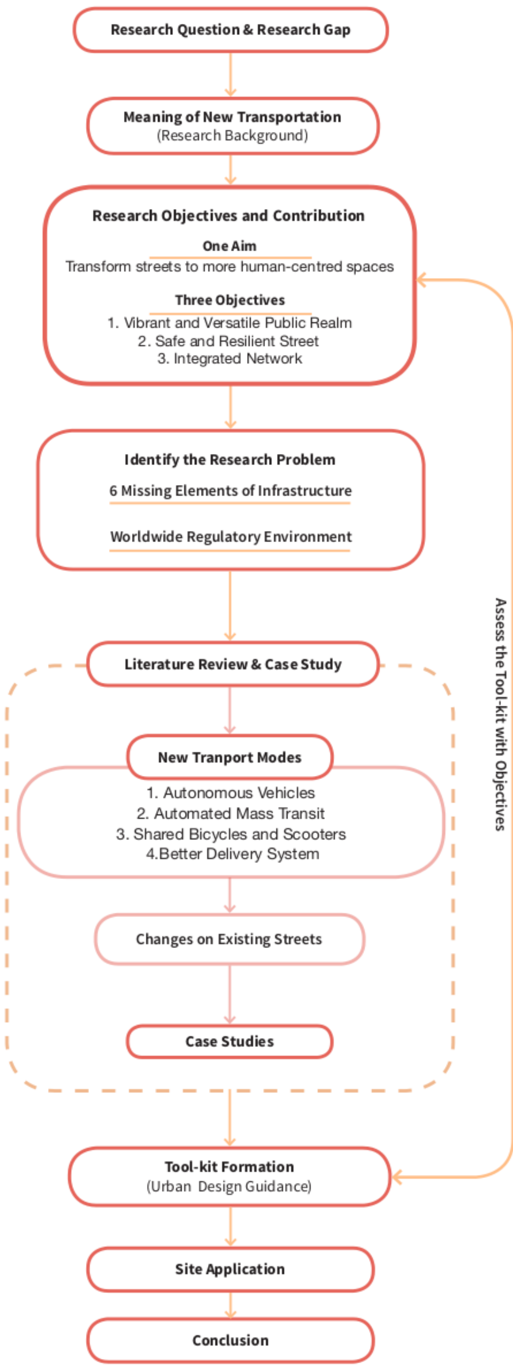


Fig. 4.1: Methodology map.

Project Site

The site is the Tianhe CBD in Guangzhou, China. In country scale, transportation in China still over relies on private cars. Up to the end of 2018, its gross road motor vehicle number exceeds 332 million which ranks the first in the world (Traffic Management Bureau of China's Ministry of Public 2018, cited in Molly, 2018). Meanwhile, China has positive attitudes towards the new transportations: The quantity of renewable-energy-powered vehicles is expected to overtake that of United States by 2020 reaching the number of 5.85 million (People's Republic of China, 2015) and the Chinese shared bicycle services have over 235 million users (iiMedia Research 2018). Huge traffic volume, dense population and positive circumstance of new transportation are all beneficial for the application of tool-kit.

As for the city scale, Guangzhou is a typical Chinese metropolis. Its centre, the CBD is the densest and most vibrant area with a complex and enormous transportation network. The overall site is around 1.1 km^2 and consists of various urban functions and comprises diverse street levels. The enormous transportation requirement and the comprehensive street hierarchy both strongly support the application of tool-kit.

Location: Guangzhou, China
Site Area: 1.1 km^2
Population: 300,000

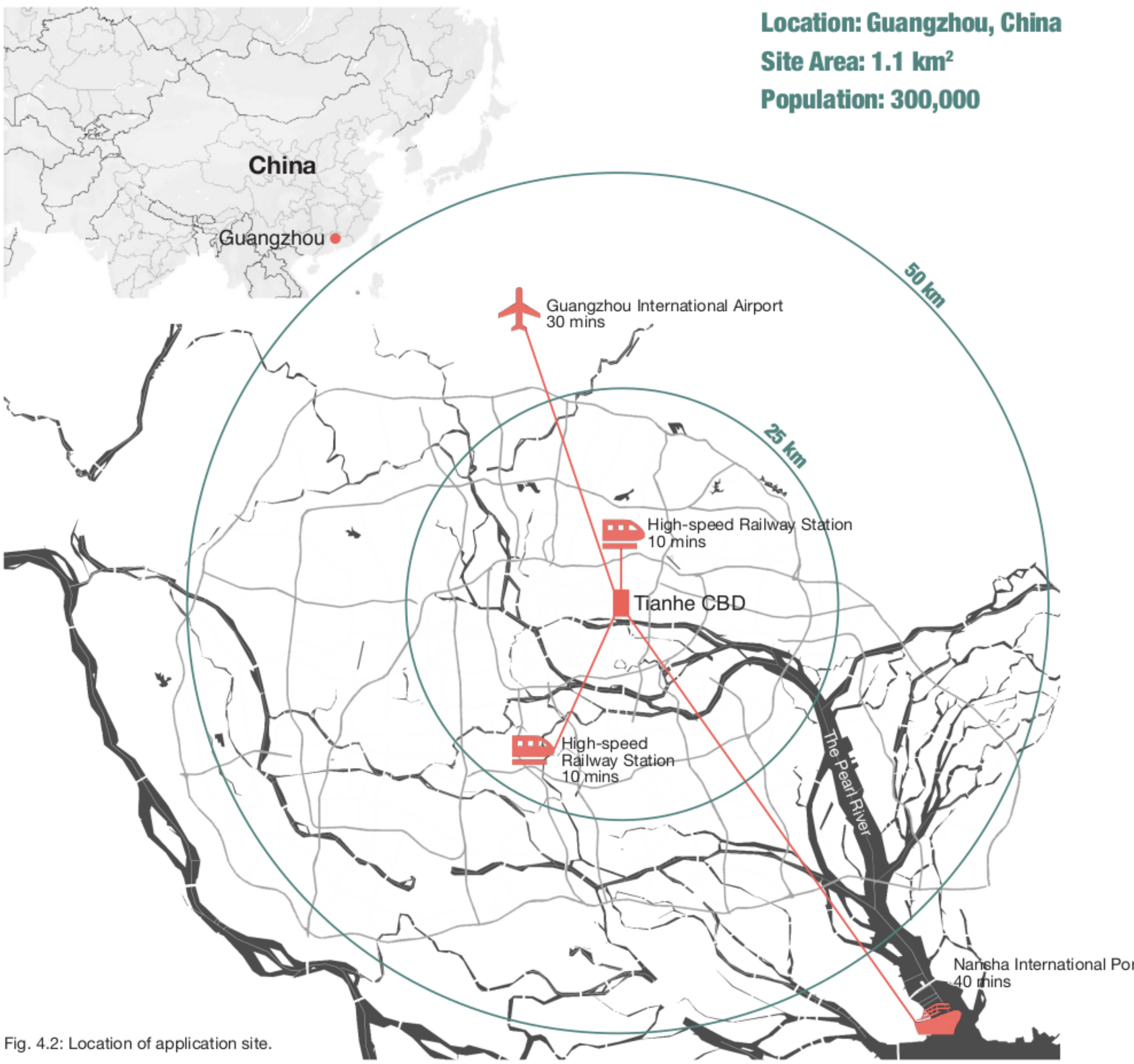


Fig. 4.2: Location of application site.

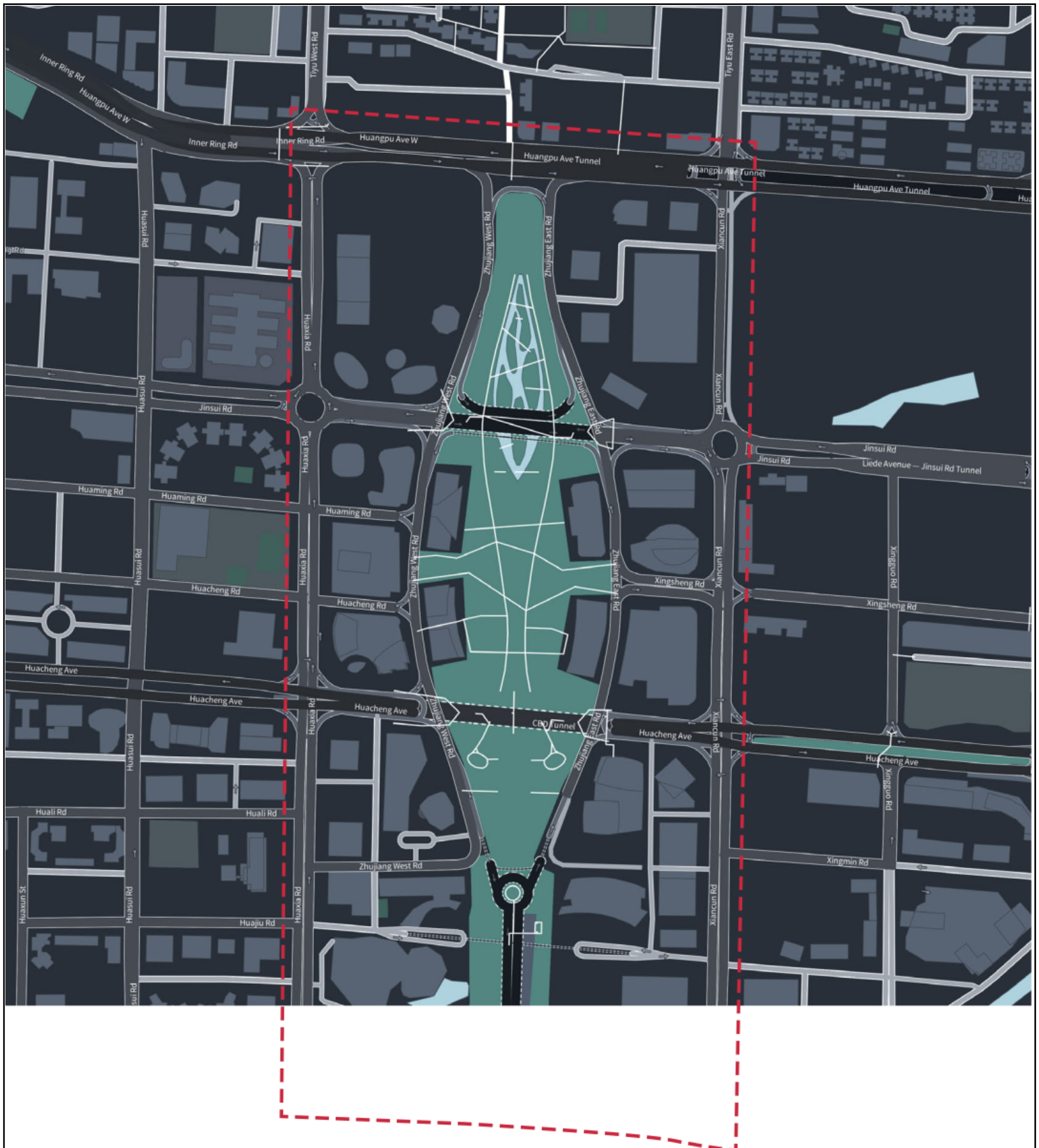
Research Timetable

Schedule	Rationale
Initial literature review & proposal 1/1-4/4/2019	To have an overlook of the whole field and identify the most relevant literature of the research topic.
In-depth literature review 4/4-1/5/2019	To review the filtered literature following the research question and problem set out in the proposal for figuring out what problems have been sorted or what theories were put forward by previous studies.
Draft tool-kit 1/5-10/5/2019	A generic tool-kit based on reviewed literature is the crucial element to solve the research problem in different circumstances.
Case study & improve the tool-kit 10/5-20/5/2019	The tool-kit needs to be improved and optimised by reviewing cases and justifying the feasibility in real life.
Site visit 20/5-5/6/2019	Collecting data and understanding local context can make the tool-kit application more reasonable and practical. Specific interview to commuters reveals the fundamental deficiencies and challenges of its transportation.
Workshop 1	
Project application 5/6-30/6/2019	To demonstrate the feasibility of the tool-kit, and also assess its impact and influence in real life.
Workshop 2	
Editing & Proofing 30/6-19/7/2019	To ensure the preciseness and correctness of writing, also optimise the logicality of the discourse.
19/7/2019 - Draft Submission	
Revision 19/7 - 2/9/2019	Revised based on supervisor's comments.
2/9/2019 - Final Submission	

Table 4.2: Research timetable.

APPLICATION

5



Label

Site Boundary

Water

Green Land

Express Way

Tunnel

Main Road

Connecting Road

Secondary Road

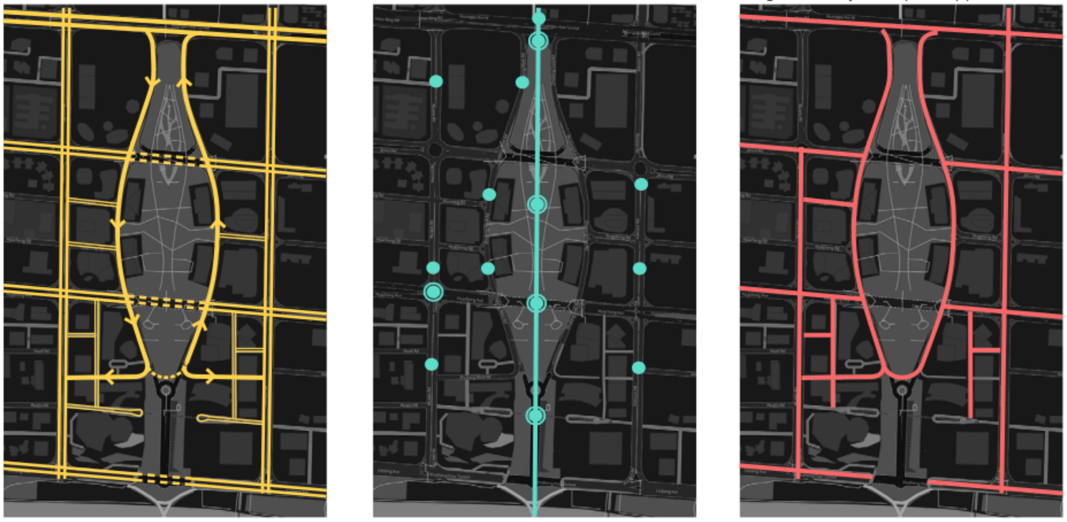
Pedestrian Path

Fig. 5.1: Map of application site.

Existing Situation

Transportation Analysis

Fig. 5.2: Analysis maps of application site.



Vehicle Flows

The internal traffic relies on an anticlockwise one-way road, and the rest of all the roads are two-way. Four east-west direction tunnels cross the site to leave the ground floor to the park.

Public Transport

There is an automated metro system passing through the site in south-north direction with four metro stations. Bus stops are mainly located on these two primary roads in the west and east.

Absence of Cycle Lanes

Most of the roads lack dedicated cycle lanes (in pink line).

Ground Floor Use Analysis

Ground floors are mainly office or retail. There are four public buildings in the south, including city library, museum, opera house and teenager centre. All of these parcels surround a huge central park.

Fig. 5.3: Ground floor use map of application site.

Investigation Statistics

Fig. 5.4: Night view of application site. Source: kknews, 2018.

1.65 million
Person-time every day on average

350 thousand
Car-time every day on average

300 thousand
Employment positions

Data source: AECOM, 2017.

Commuting Way Investigation

The interview sample is 100 randomly chosen people in Tianhe CBD. Three questions were asked:

How do you commute everyday?
How's your walking experience?
How's your Cycling experience? (For those who cycle)

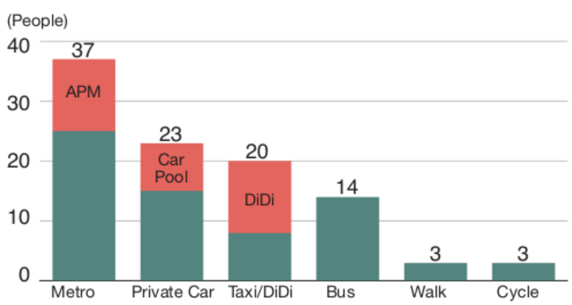


Fig. 5.5: Commuting modes distribution.

32 %
Satisfaction degree of walking

23 %
Satisfaction degree of cycling

Active Mobility Proportion Comparison

Data source: Sohu, 2017.

32% Tianhe CBD

50 % Berlin

53% Rotterdam

47 % Shanghai

Problems

Road Condition

Road system here is built for automobiles. This kind of street with multiple car lanes and high speed can be found in many places in the area. Although some of them are equipped with cycle lanes, but no one wants to cycle in such roads.

Fig. 5.6: Intersection of Huaxia Road.

Cycling Experience

A sufficient number of streets here have no dedicated cycle lanes which force Cyclists to share the same space with cars, which sometimes causes traffic accidents.

Fig. 5.7: Cycle condition in Tianhe CBD.

Walking Experience

Roads are too wide to cross, and there are few crossing gateways. Pedestrians have to detour a long distance to find one, and some of them cross the road directly.

Fig. 5.8: Pedestrian condition in Tianhe CBD.

Ground Vibrancy

According to the human activity map and land-use, the most vibrant place in the area is a metro station entrance. Retail facilities in orange have few pedestrian flows surrounding.

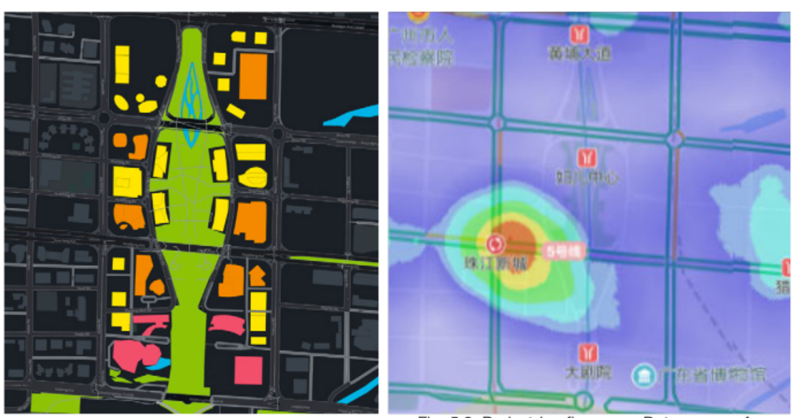
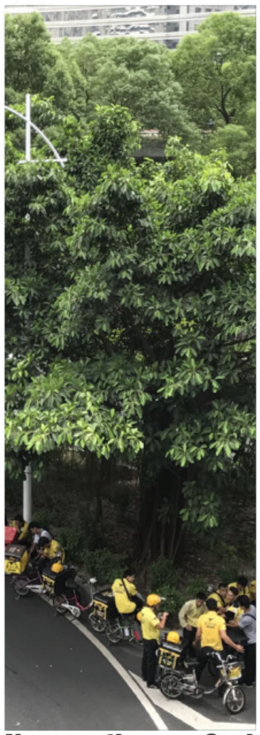


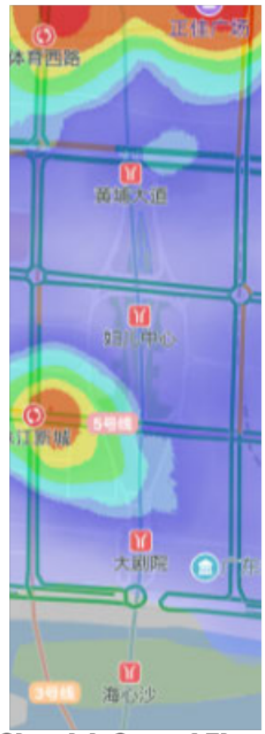
Fig. 5.9: Pedestrian flow map. Data source: Amap.

Vehicle-oriented Transportation System

Unsatisfying Walking Experience



Non-continuous Cycle Network



Sluggish Ground Floor

This is not a human-centred place.

Strategy One: Revive Street

Relevant Tools: Integrated Service Hub, Street Garden, Crossing Gateway, Smart Intersection

Solved Problems: Road Condition, Cycling Experience

This strategy aims at reviving the internal anticlockwise street, which has four one-way lanes but lacks cycle lane at present. A new two-way cycle highway which showed in blue on the map is supplemented and extended to the south to link the existing river bank cycle lane.

An integrated service hub is deployed in the north, and a new autonomous shuttle bus is connected to provide a better alternative commuting way. It is an action to reduce private car usage within site.

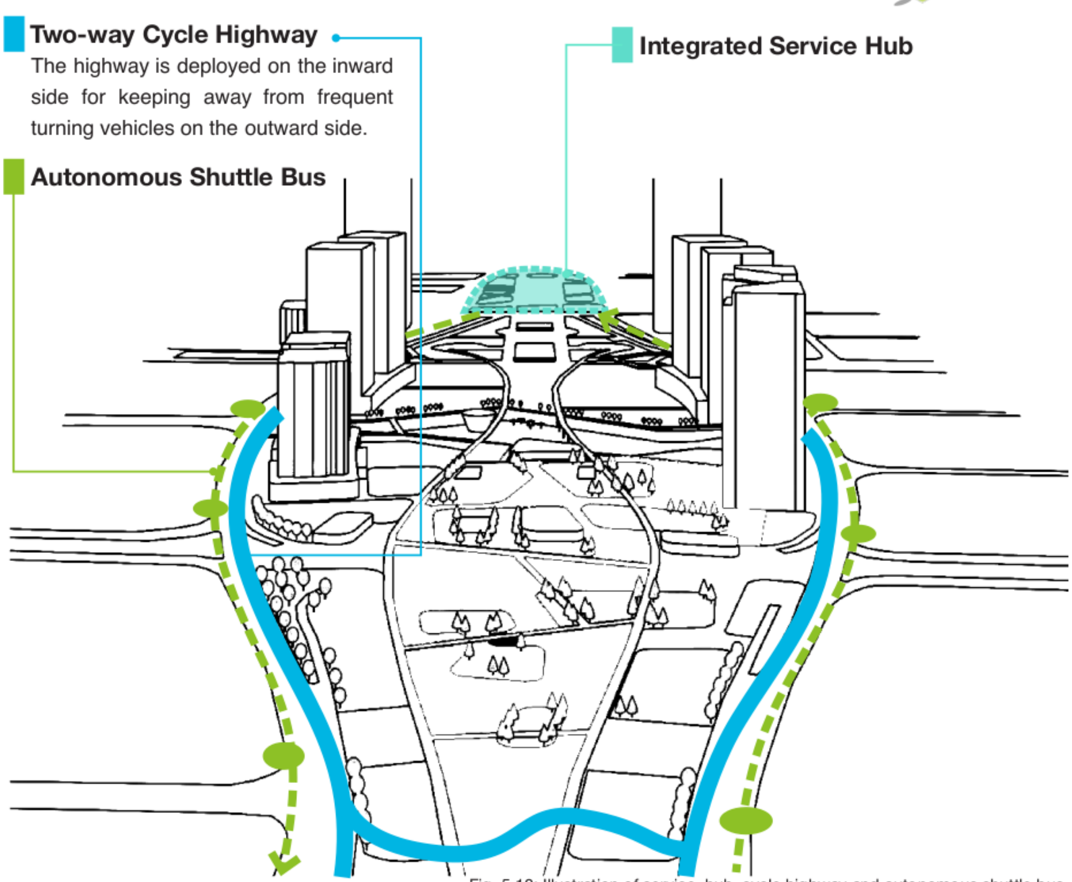


Fig. 5.10: Illustration of service hub, cycle highway and autonomous shuttle bus.

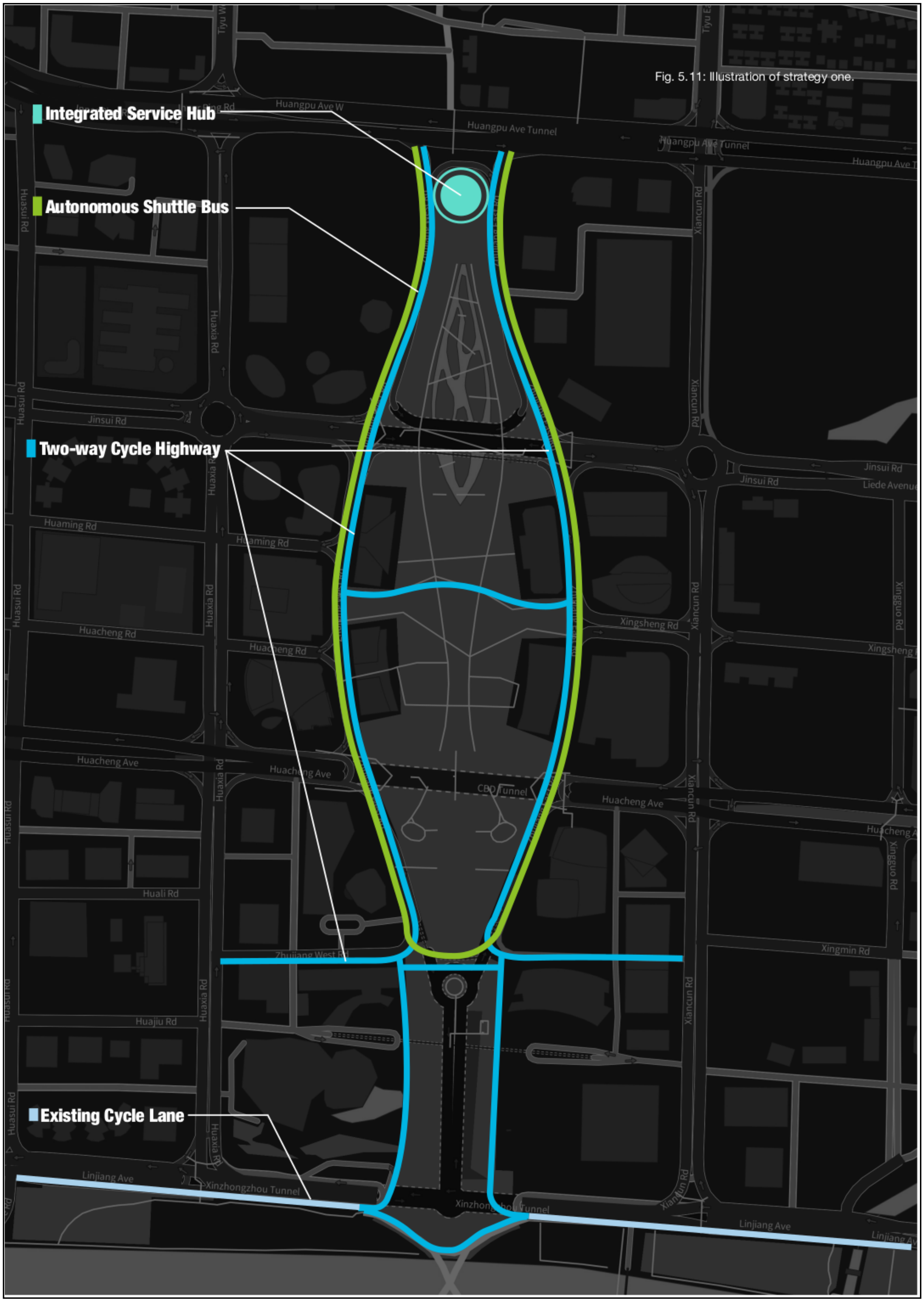


Fig. 5.11: Illustration of strategy one.

Strategy Two: Smart Block

Relevant Tools: Versatile Kerbside, Street Garden

Solved Problems: Road Condition, Walking Experience, Ground Vibrancy

This strategy mainly focuses on the application of versatile kerbside, which is the key to transform streets from linear transport spaces to multifunctional places. By encouraging diverse activities on kerbside, adjoining retail and building frontages can be activated. People working nearby can have new public realm for communication and resting.

Transport-oriented Kerbside

Versatile Kerbside

Chosen Block

The outside kerbs adjoining the main roads are transport-oriented since they connect the busy transport streets with high demands of drop-off and pick-up throughout the day.

On the other sides close to that anticlockwise street, are versatile kerbs with shifting functions that are mentioned in the tool-kit section.

The proposal has considered the position of garage entrances to avoid the conflict with vehicle flows.

Fig. 5.12: Example of smart blocks.

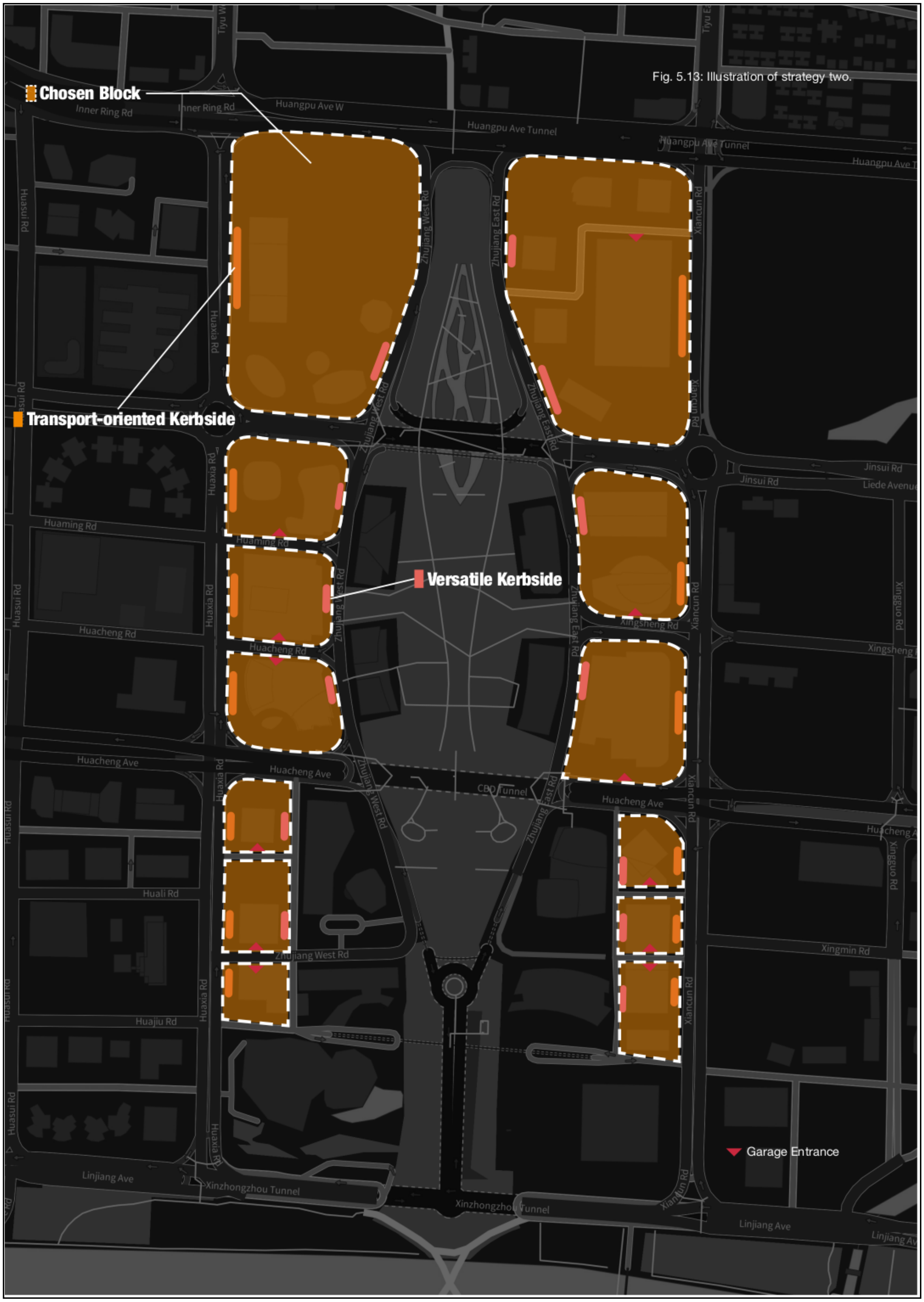


Fig. 5.13: Illustration of strategy two.

Strategy Three: Optimise Non-motorised Network

Relevant Tools: Smart Intersection, Crossing Gateway, Street Garden

Solved Problems: Road Condition, Cycling Experience, Walking Experience, Ground Vibrancy

The last strategy is to optimise the non-motorised network and improve cycling and walking experience. Three tools are deployed in this strategy:

Optimised Pavement and Cycle Lane

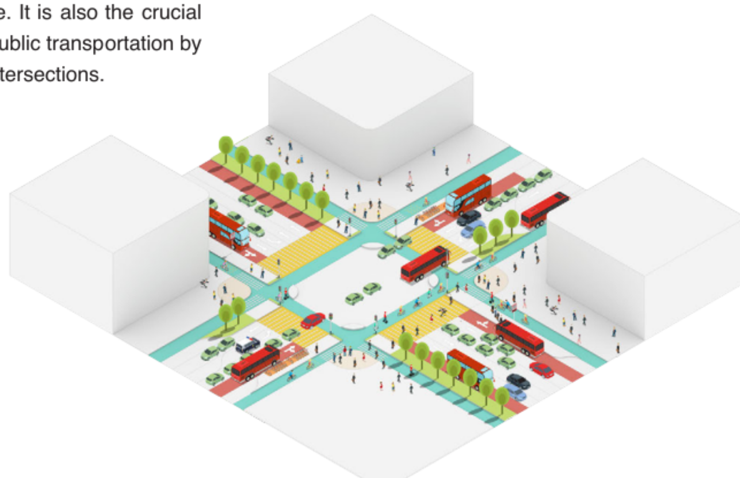
Optimised pavement and supplementary cycle lanes are added to streets lacking them. This action works with the cycle high way in strategy one to form a complete active mobility network.

Crossing Gateway

Crossing gateways can help to enhance the connection among different plots and lead the pedestrians to the central park. Unlike conventional speed bumps, this facility can instruct approaching vehicles to slow down without annoying passengers.

Smart Intersection

Smart Intersections are deployed to promote traffic efficiency and safety across the site. It is also the crucial action to encourage cycling and public transportation by providing a better experience in intersections.



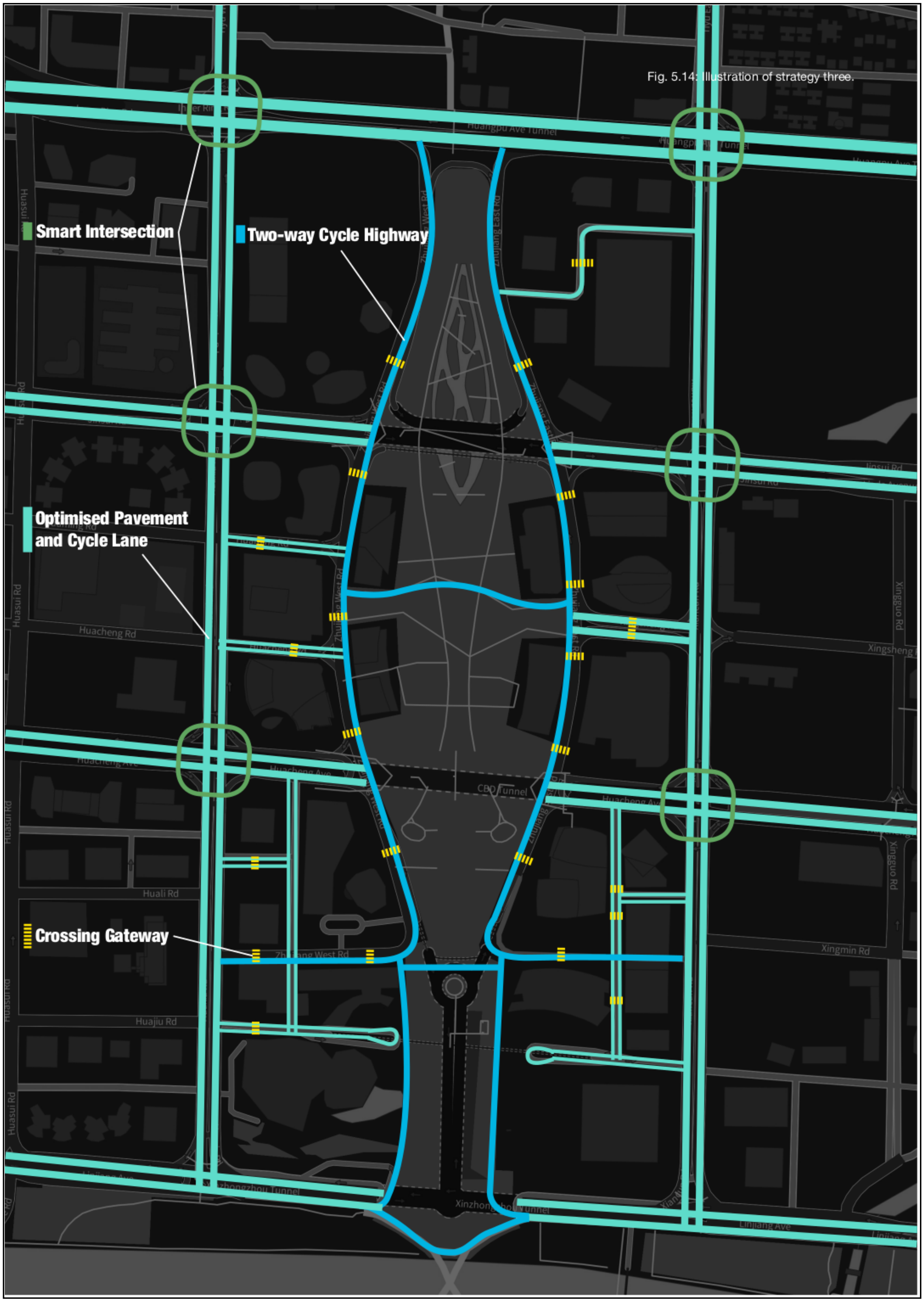


Fig. 5.14: Illustration of strategy three.

Strategy Three

Prospect of Smart Intersection - Cooperative Intersection Network

All those intersections can cooperate closely to promote traffic efficiency. The information including turning direction, speed, vehicle volume, cyclist volume, pedestrian volume and emergency is collected in each intersection then mutual communication among those intersections form a comprehensive traffic data network for guiding AVs to select the best route for passing the area. Moreover, the whole process is imperceptible since the traffic system itself can learn how to avoid congestion before it happens.

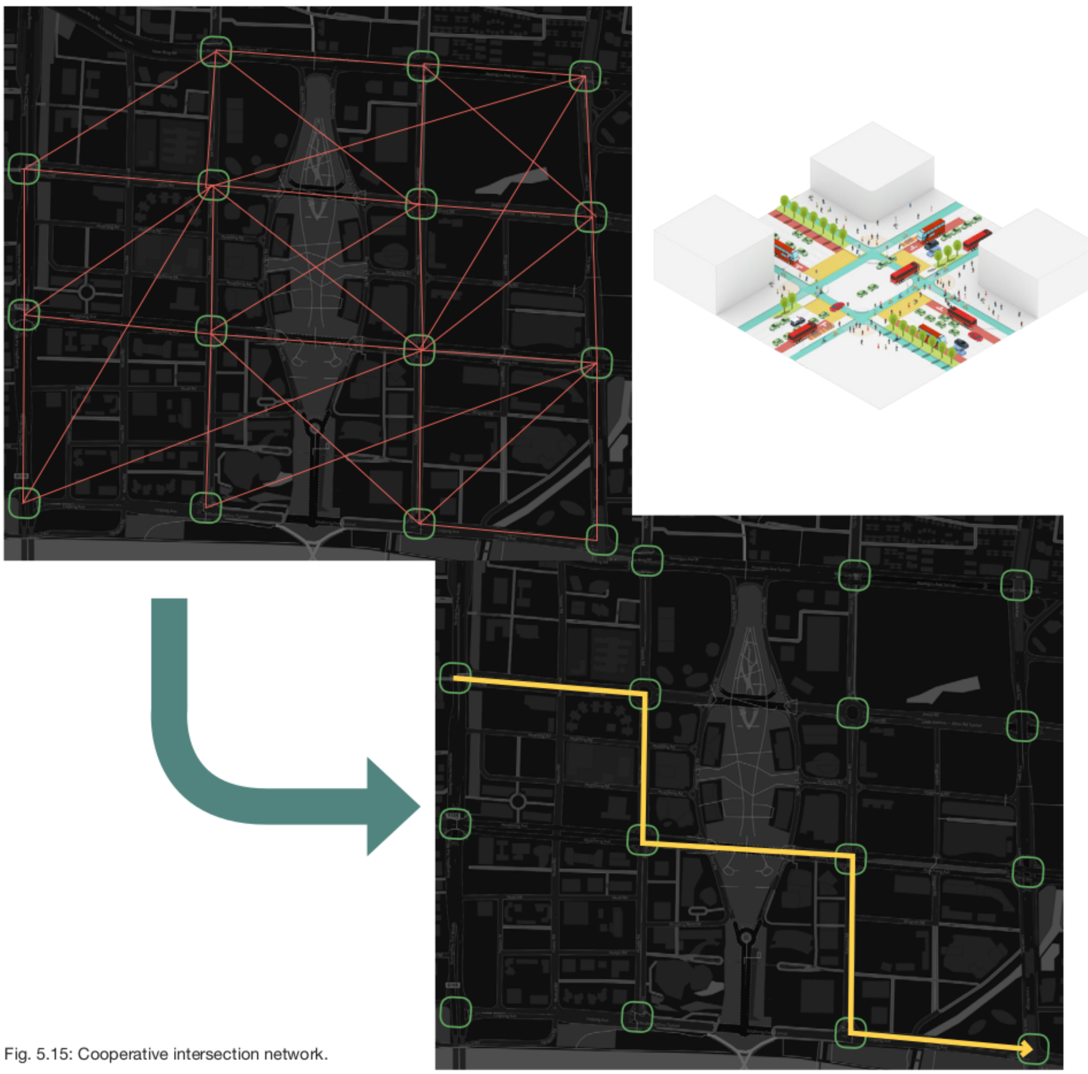


Fig. 5.15: Cooperative intersection network.

Justification of Strategy Application

The internal circular street is affected by all three strategies. Below is the justification about why it is the best choice to be transformed into completely human-centred places.

Geometrically, the potential road should have a low choice degree so that it can get rid of high traffic volume. Secondly, the road should have a higher integration level, which connotes better accessibility. That ensures people are willing to come to this place. So this anticlockwise street is the best choice to deploy all those tools.

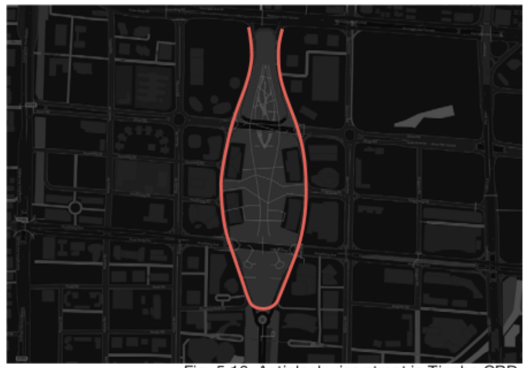


Fig. 5.16: Anticlockwise street in Tianhe CBD.

Space Syntax Analysis (Radius: 2 km)

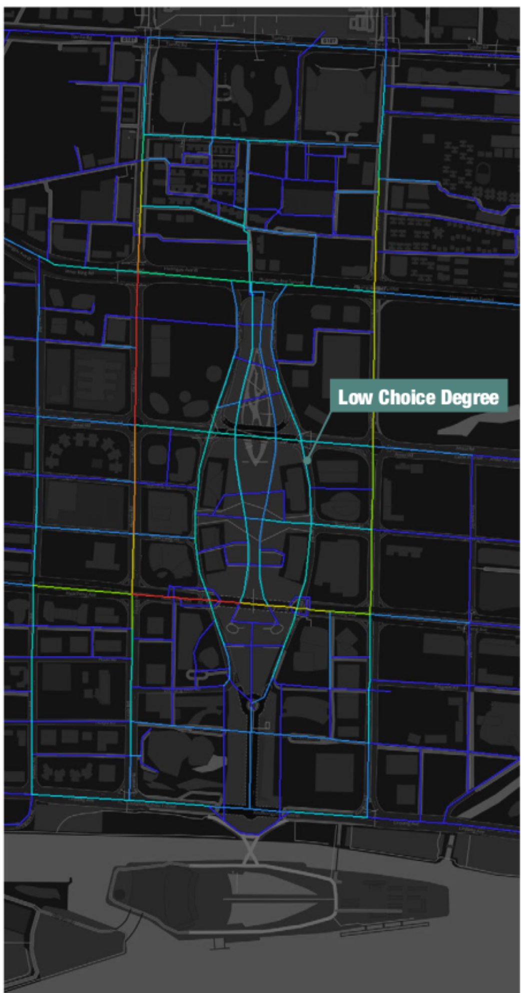


Fig. 5.17: Space Syntax analysis - choice level.

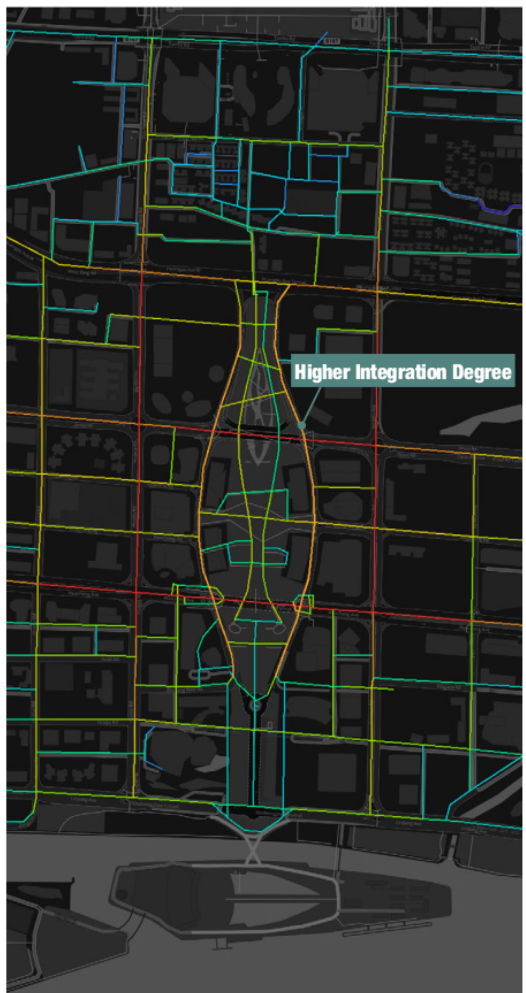


Fig. 5.18: Space Syntax analysis - integration level.

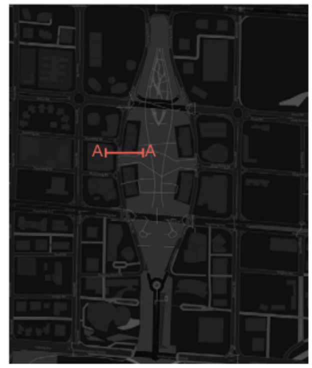


Fig. 5.19: Section position.

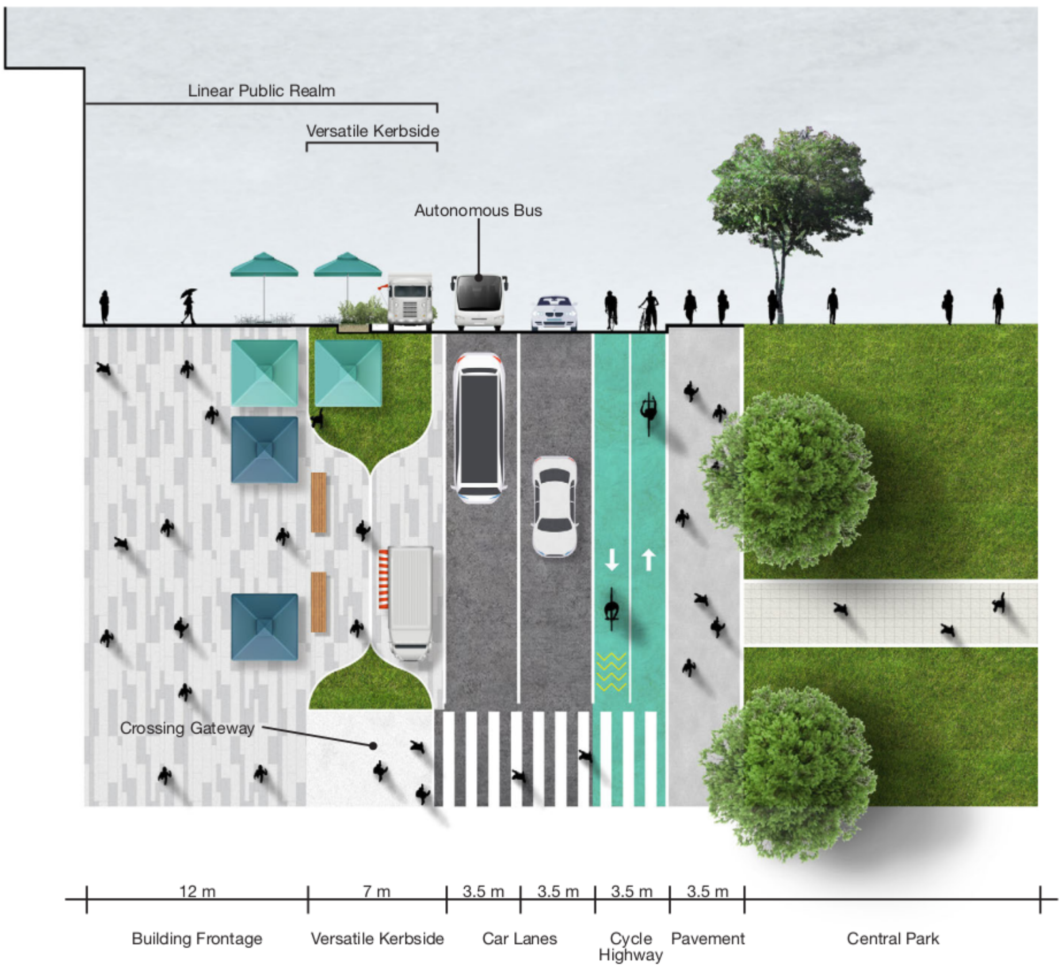
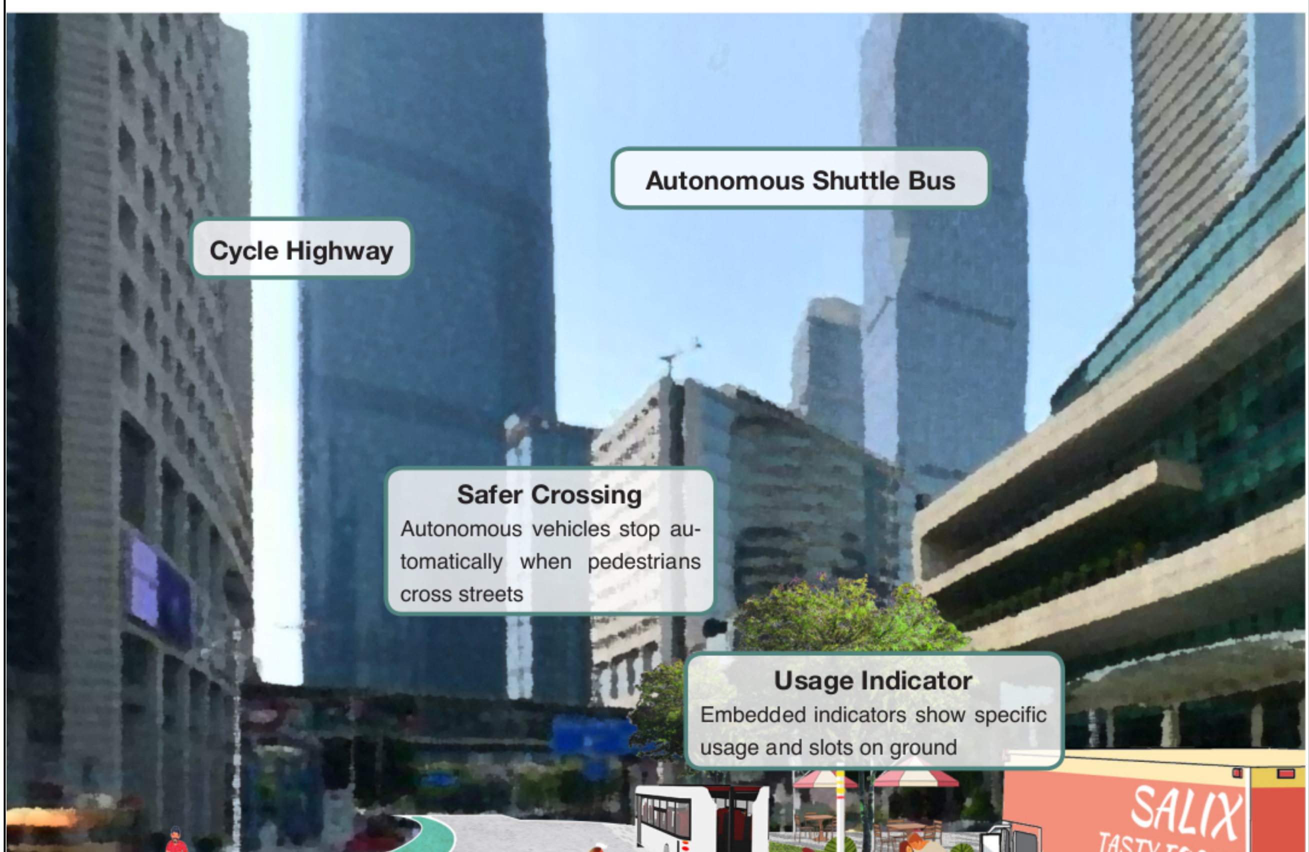


Fig. 5.21: Section A-A after transformation.

Design Prospect: Zhujiangxi Road

Fig. 5.23: Proposed design of the Zhujiangxi Road.



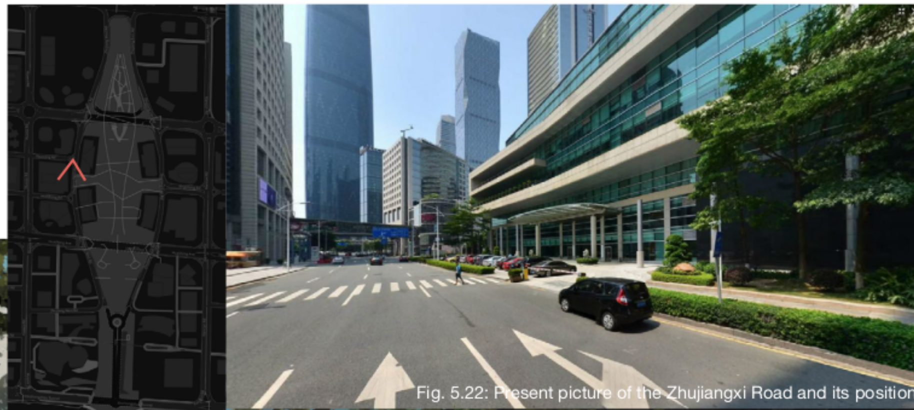


Fig. 5.22: Present picture of the Zhujiangxi Road and its position.

Design Prospect: West-east Cycle Lane

Fig. 5.24: Proposed design for cycle lane and its position.


Period-management reminds cyclists to slow down speeds during off-peak hours to balances the connection of cycle lanes and the experience of pedestrians.
Now 10:34
Slow down during 10:00-12:00

Design Prospect: Integrated Service Hub

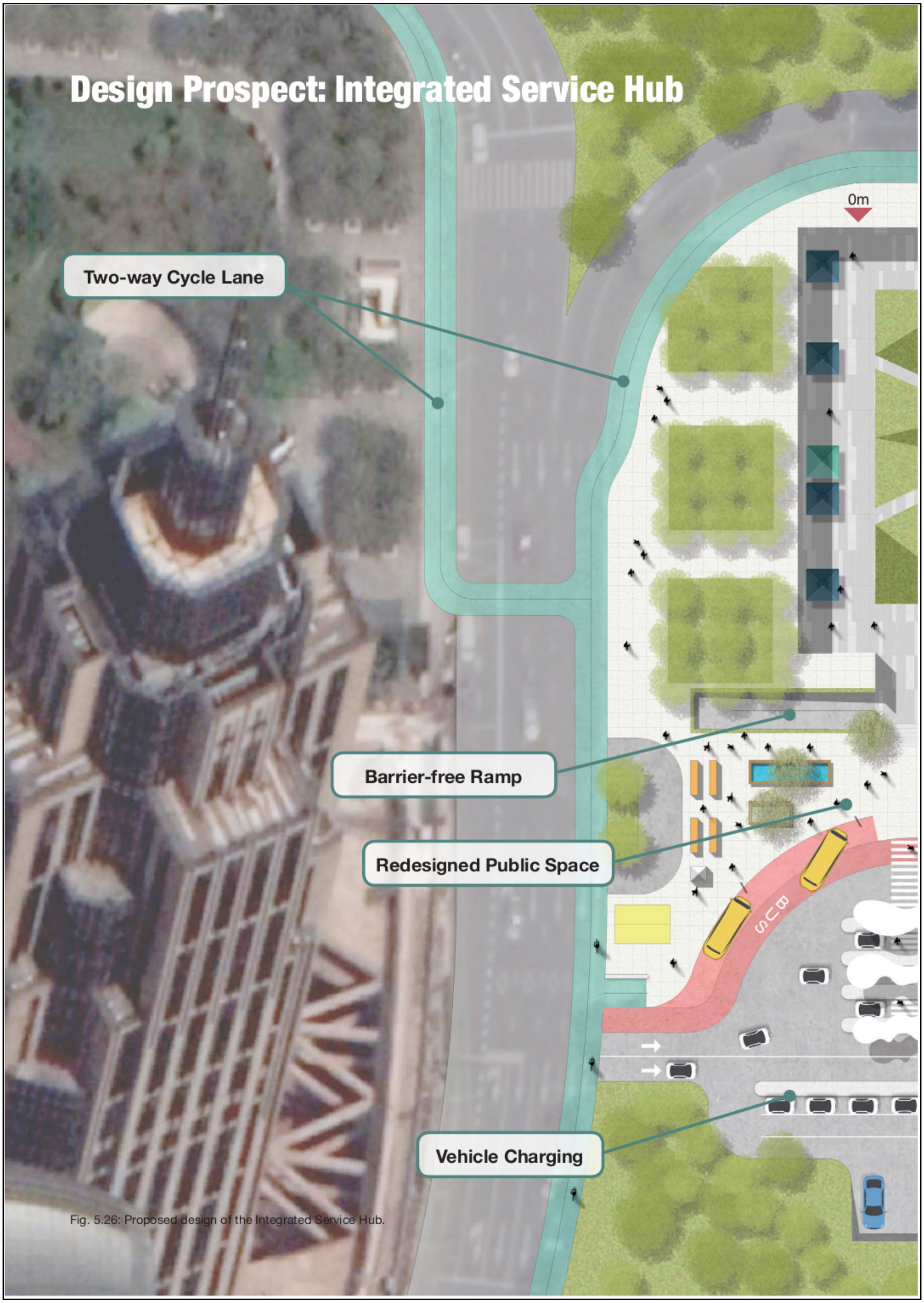


Fig. 5.26: Proposed design of the Integrated Service Hub.

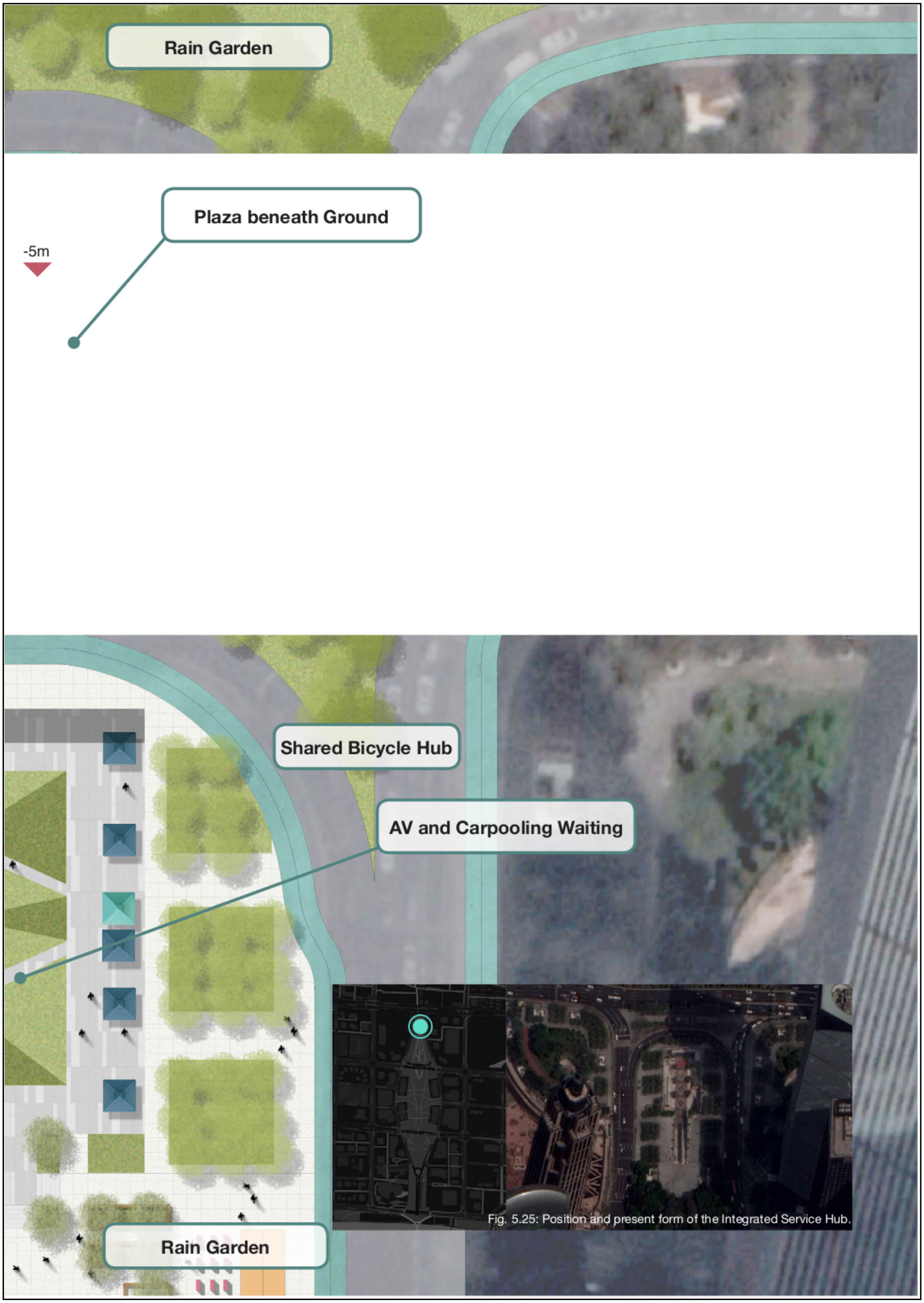


Fig. 5.25: Position and present form of the Integrated Service Hub.

Design Prospect: Intersection

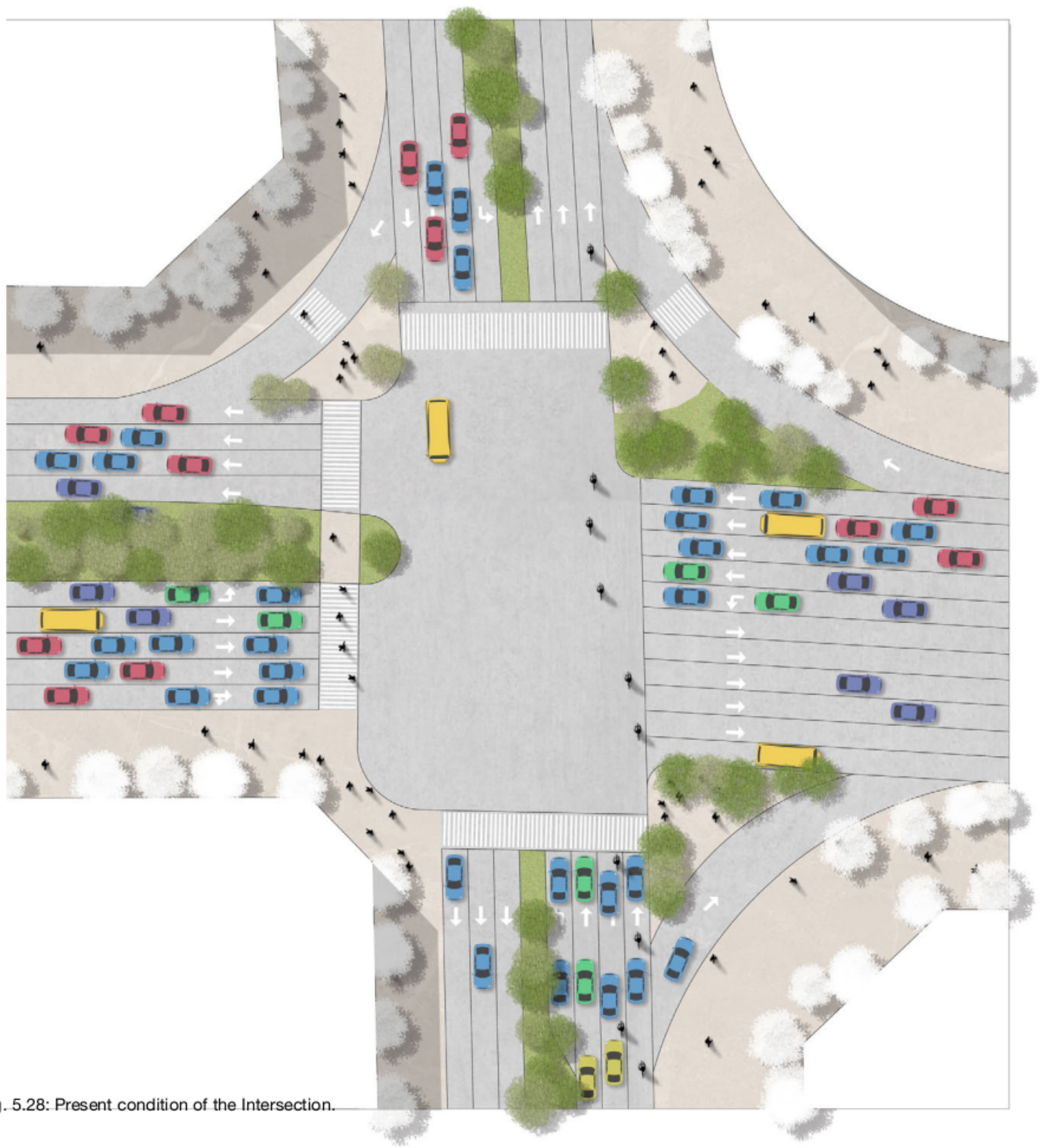


Fig. 5.28: Present condition of the Intersection.

Fig. 5.27: Position of the Intersection.

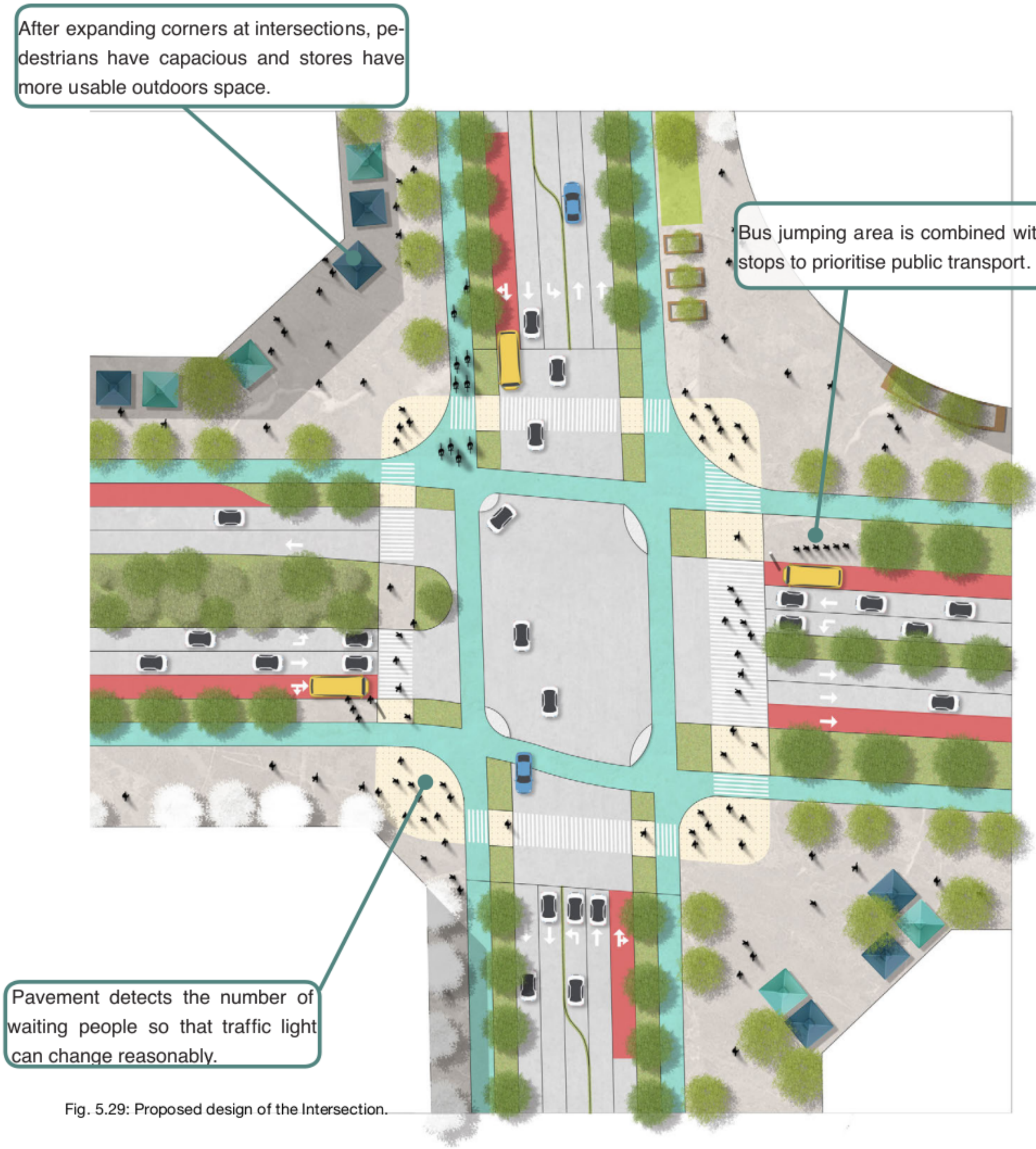


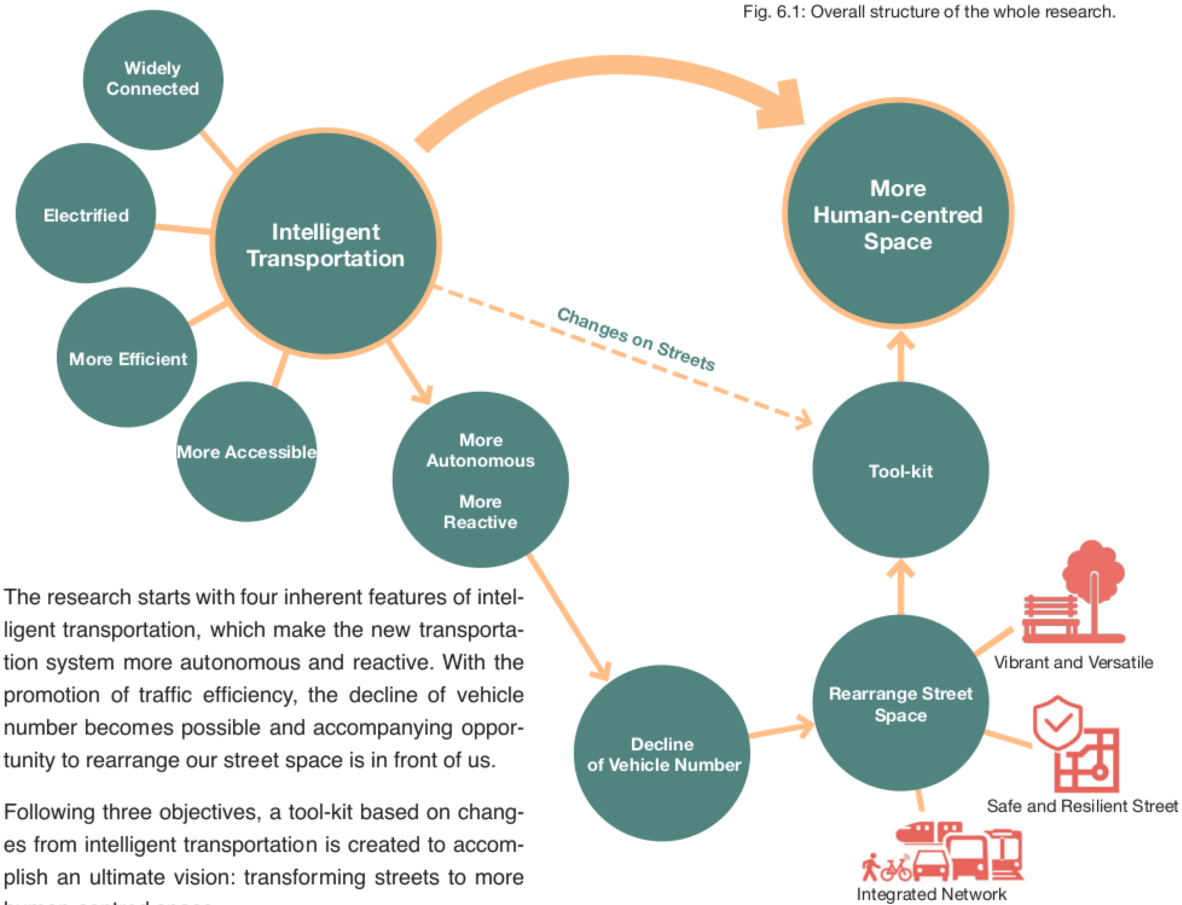
Fig. 5.29: Proposed design of the Intersection.

CONCLUSION

6

Reiteration of Research Content

Fig. 6.1: Overall structure of the whole research.



The research starts with four inherent features of intelligent transportation, which make the new transportation system more autonomous and reactive. With the promotion of traffic efficiency, the decline of vehicle number becomes possible and accompanying opportunity to rearrange our street space is in front of us.

Following three objectives, a tool-kit based on changes from intelligent transportation is created to accomplish an ultimate vision: transforming streets to more human-centred space.

Contribution of Research

Fig. 6.2: Transformation of road form.

At most time, our streets are regarded as a space with clear demarcation. Vehicles and people are constrained within a certain space in a still condition. However, human behaviours and transportation are dynamic.

This research takes the new transport system as an opportunity to redesign our streets by modularising flexible spaces. It transforms streets from linear traffic space to multifunctional public realm with the developed tool-kit.

It blurs the previous demarcation and makes streets more flexible to accommodate various activities dynamically. The research helps those high-density areas to develop available public space from existing urban skeleton rather than occupying extra land or demolishing built environment.

Limitation of Research

In this research, four new transportation modes are discussed, and the choice of them is based on their relatively mature development, high possibility of widespread deployment and strong support from previous research and literature. However, other technologies might change transportation such as delivery drones, flying taxi service, super-speed underground tunnels and modularised automated light train. The impact on urban space of those technologies could be studied in future while they become more feasible and mature.

Because of the present development of the industry, a built project which successfully applied all four technologies cannot be found as a reference, which is another limitation of this research. The proposed tools are based on respective precedents, and that might ignore the synergy or conflict between different traffic modes.

Moreover, the assessment of the tool-kit is qualitative instead of quantitative due to the lack of transportation simulation or related quantitative analysis. This could reduce the viability of tool-kit performance and benefits. In further research, programs such as Adobe Infraworks can be used to simulate the traffic impact of those areas with tool-kit applied for presenting more precise influence.

Further Research Opportunity

Research Background

Different view points

Focus of This Research

Fig. 6.3: Relevant topics in the same field.

New transportation system is a broad topic, and this research only discusses part of the corresponding spatial design on streets.

In the same subtopic of spatial design, more specific design guidance referring to the measurement of certain components, typology of different types of streets and variation under different cultural backgrounds can be investigated in future research.

Beyond this subtopic, the relevant policy framework is another significant aspect that impacts urban space and transportation evolution in future. On the other hand, the progress of technologies changes rapidly and sometimes unpredictable. That brings both opportunities and challenges to city planners, and the potential of emerging technologies can always inspire further research and generate new concepts. Furthermore, the ethics side of the new transportation system is controversial all the time. For example, how can we judge who should take responsibility for a fatal accident caused by autonomous a car or will autonomous vehicles substitute for all human drivers and lead to industrial unemployment?

In conclusion, this research only reveals a possible prospect of urban streets while facing the advent of new transportation but diverse entry points can be found from different aspects for discussing the future further.

Reference List

Acharya, K., (2017). Can a Trash Can Reveal a Community's Values? [online]. *Gehlinstitute*. [Viewed 5 April 2019]. Available from: https://gehlinstitute.org/dialogue/can-trash-can-reveal-communitys-values/

Alrutz, D., Angenendt, W., and Draeger, W., (2012).Traffic safety on one-way streets with contraflow bicycle traffic [online]. *Bikexprt*. [Viewed 2 February 2019]. Available from:http://bikexprt.com/research/contraflow/gegengerichtet.htm

Beyer, S., (2015). Can Los Angeles Solve Its Traffic Problem By Building More Roads? [online]. *Forbes*. [Viewed 21 February 2019]. Available from: https://www.forbes.com/sites/scottbeyer/2015/11/23/can-los-angeles-solve-its-traffic-problem-by-building-more-roads/#79dd6cf7234d

Brian, H., (2002). *London Underground Rolling Stock*.15th ed. Harrow Weald: Capital Transport.

Brookes, W., (2019). Public Acceptance: Have Autonomous Vehicles Become Reality? [online]. *2050ad*. [Viewed 13 February 2019]. Available from: http://2025ad.cn/article/OTM2Mw==.html

Campbell, L., (2012). Amazon partners with Co-op for collection lockers [online]. *The Bookseller*. [Viewed 12 February 2019]. Available from: https://www.thebookseller.com/news/amazon-partners-co-op-collection-lockers

Chao, L., (2015). 7-Eleven Expands Locker Space, Hoping to Cash In on E-Commerce Wave [online]. *Wall Street Journal*. [Viewed 6 April 2019]. Available from: https://www.wsj.com/articles/7-eleven-expands-locker-space-hoping-to-cash-in-on-e-commerce-wave-1447326538

Chong, J., (2017). Lowering the barriers to combined control rooms [online]. *ITS International*. [Viewed 14 February 2019]. Available from:https://www.itsinternational.com/categories/utc/features/lowering-the-barriers-to-combined-control-rooms

Clark, S. D. and Page, M. W., (2000). Cycling and Urban Traffic Management and Control Systems. *Transportation Research Record* [online]. **1705**. 77-84. [Viewed 6 April 2019]. Available from: https://www.researchgate.net/publication/235357871_Cycling_and_Urban_Traffic_Management_and_Control_Systems

Colijn, P., Herbach, J. H., and McNaughton, M. P., (2017). Determining pickup and destination locations for autonomous vehicles [online]. *Google Patents*. [Viewed 3 March 2019]. Available from: https://patents.google.com/patent/US9733096B2/en

Collinson, P., (2017). On your bike: the best and the worst of city cycle schemes [online]. *The Guardian*. [Viewed 6 March 2019]. Available from: https://www.theguardian.com/money/2017/feb/25/best-and-worst-city-cycle-schemes-bike-sharing-london

Corbusier, L., (1943). The Athens Charter CIAM 4. New York: Grossman Publishers.

CORDIS, (2016). Final Report Summary - CITYMOBIL2 (Cities demonstrating cybernetic mobility) [online]. *CORDIS*. [Viewed 13 February 2019]. Available from: https://cordis.europa.eu/project/rcn/105617/reporting/en

Crainic, T. G., Ricciardi, N., and Storchi, G., (2004). Advanced freight transportation systems for congested urban areas. *Transportation Research Part C: Emerging Technologies* [online]. **12**(2),119-137. [Viewed 3 April 2019]. Available from: https://doi.org/10.1016/j.trc.2004.07.002.

David, D., (2015). The Driverless Car Is (Almost) Here [online]. *AARP*. [Viewed 24 February 2019]. Available from: https://www.aarp.org/home-family/personal-technology/info-2014/google-self-driving-car.html

Dixon, S., Irshad H., Pankratz D. M., and Bornstein J., (2019). *The 2019 Deloitte City Mobility Index: Gauging global readiness for the future of mobility*. London: Deloitte Insights.

Edgar, D., (2017). *Cyclists using the new cycle lane on Oxford Road, Manchester, passing an electronic counter across the road from Whitworth Park* [digital image]. [Viewed 24 February 2019]. Available from: https://commons.wikimedia.org/wiki/File:Cycle_lane_on_Oxford_Road,_Manchester_with_counter.jpg

Fagnant, D. J. and Kockelman, K., (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice* [online]. **77**,167-181.[Viewed 26 February 2019]. Available from: https://doi.org/10.1016/j.tra.2015.04.003.

Federal Highway Administration, (2009). The National Intersection Safety Problem [online]. *Federal Highway Administration*. [Viewed 1 January 2019]. Available from: https://safety.fhwa.dot.gov/intersection/other_topics/fhwa-sa10005/brief_2.cfm

Fishman, T. D., (2014). *Digital-Age Transportation: The Future of Urban Mobility* [online]. London: Deloitte University Press. [Viewed 2 January 2019]. Available from: https://www2.deloitte.com/tr/en/pages/public-sector/articles/digital-age-transportation-article.html

Frost & Sullivan, (2018). *Global Autonomous Driving Market Outlook* [online]. Los Angeles: Frost & Sullivan. [Viewed]. Available from: https://info.microsoft.com/rs/157-GQE-382/images/K24A-2018%20Frost%20%26%20Sullivan%20-%20Global%20Autonomous%20Driving%20Outlook.pdf

Geetha, S. and Cicilia, D., (2017). *IoT enabled intelligent bus transportation system* [online]. Coimbatore: International Conference on Communication and Electronics Systems. [Viewed 21 February 2019]. Available from:doi: 10.1109/CESYS.2017.8321235

Global Designing Cities Initiative and National Association of City Transportation Officials, (2019). *Global Street Design Guide*. Washington: Island Press.

Goodchild, A. and Ivanov, B., (2017). The Final 50 Feet of the Urban Goods Delivery System [online]. Washington: University of Washington. [Viewed 6 February 2019]. Available from: https://depts.washington.edu/sctlctr/sites/default/files/SCTL_Final_50_full_report.pdf

Gruel, W. and Stanford, M. J., (2016). Assessing the Long-term Effects of Autonomous Vehicles: A Speculative Approach. *Transportation Research Procedia* [online]. **13**, 18-29. [Viewed 27 February 2019]. Available from: https://doi.org/10.1016/j.trpro.2016.05.003.

Heinen, E., Wee, B. V., and Maat, K., (2010). Commuting by Bicycle: An Overview of the Literature [online]. *Transport Reviews*. **30**(1), 59-96. [Viewed 10 February 2019]. Available from: DOI: 10.1080/01441640903187001

Hkobserver, (2016). Smog in Beijing Contains Antibiotics [online]. *Hkobserver*. [Viewed 23 February 2019]. Available from: http://www.hkobserver.com/index.php/2016-08-03-09-22-38/1680-2016-11-26-17-03-39

Honig Z., (2016). 8 Things to Know About Using Uber in Las Vegas [online]. *The Points Guy*. [Viewed 5 January 2019]. Available from: https://thepointsguy.com/2016/06/using-uber-in-vegas/

Hudson, A., Freemark, Y., and Zhao J., (2019). Are cities prepared for autonomous vehicles? Planning for technological change by U.S. local governments [online]. *Urban Mobility Lab at MIT*. [Viewed 7 January 2019]. Available from: https://mobility.mit.edu/publications/9998/freemark-are-cities-prepared-autonomous-vehicles-planning-technological-change-us

IEC., (2014). Railway applications - Urban guided transport management and command/control systems - Part 1: System principles and fundamental concepts [online]. *International Electrotechnical Commission*. [Viewed 10 March 2019]. Available from: https://webstore.iec.ch/publication/6777

IEEE., (2016). Finland launches automated buses in three cities [online]. *IEEE*. [Viewed 19 March 2019]. Available from: http://sites.ieee.org/connected-vehicles/2016/07/14/finland-launches-automated-buses-three-cities/

Ifeng, (2017). Twelve Cities Have Stopped Shared Bicycles [online]. *Ifeng*. [Viewed 12 March 2019]. Available from: http://tech.ifeng.com/a/20170907/44675443_0.shtml

Inpost, (2017). Host and Inpost Parcel Locker [online]. Inpost. [Viewed 24 February 2019]. Available from: https://inpost.co.uk/en/work-with-us/host-a-locker

Kaichsmartcity, (2018). Intelligent Upgrade of Bus Shelter Square Welcome The First Customers Vsit Inspection [online]. *Kaichsmartcity*. [Viewed 6 March 2019]. Available from: http://www.kaichsmartcity.com/intelligent-upgrade-of-bus-shelter-square-welcome-the-first-customers-vsit-inspection/

Korosec, K., (2019). Waymo launches self-driving car service Waymo One [online]. *Techcrunch*. [Viewed 4 March 2019]. Available from: https://techcrunch.com/2018/12/05/waymo-launches-self-driving-car-service-waymo-one/?-guccounter=1&guce_referrer_us=aHR0cDovL3RlY2huZXdzLnR3LzIwMTgvMTIvMDYvd2F5bW8tbGF1bm-NoZXMtc2VsZi1kcml2aW5nLWNhci1zZXJ2aWNlLXdheW1vLW9uZS8&guce_referrer_cs=vRkmmLpGpCilqiXzcp-weHg

Land Transport Authority, (2018). *A parking space for shared bicycles in Singapore* [digital image]. [Viewed 28 March 2019]. Available from: https://sg.news.yahoo.com/lta-accept-license-applications-bike-sharing-operators-8-may-131655278.html

Lia, F., Nocerino, R., Bresciani, C., Colorni, A., and Luè, A., (2014). Promotion of E-bikes for delivery of goods in European urban areas: an Italian case study. Paris: Transport Research Arena.

Litman, T., (2019). *Autonomous Vehicle Implementation Predictions Implications for Transport Planning* [online]. London: Victoria Transport Policy Institute. [Viewed 1 January 2019]. Available from: https://www.vtpi.org/avip.pdf

Liu, H., (2019). The Miner Alteration of Communities in Chinese CBD [online]. *ChinaDaily*. [Viewed 16 March 2019]. Available from: http://ex.chinadaily.com.cn/exchange/partners/77/rss/channel/cn/columns/qq32g5/stories/WS5c9b18eaa310e7f8b15730ed.html?group_id=6672957653058060811&app=

Marx, P., (2019). Waymo CEO: 'Level 5' fully-autonomous vehicles will never exist [online]. MacDailyNews. [Viewed 5 February 2019]. Available from: https://macdailynews.com/2019/01/07/waymo-ceo-level-5-fully-autonomous-vehicles-%E2%80%8Awill-never-exist/

Maxwell, W. J., (2016). World's First Self-Driving Taxis Hit the Road in Singapore [online]. Wall Street Journal. [Viewed 8 January 2019]. Available from: https://www.wsj.com/articles/worlds-first-self-driving-taxis-hit-the-road-in-singapore-1472102747

McLeod, F. and Cherrett, T., (2011). Loading bay booking and control for urban freight. *International Journal of Logistics Research and Applications* [online]. **14**(6), 385-397. [Viewed 9 January 2019]. Available from: DOI: 10.1080/13675567.2011.641525

Mitchell, M. J., Borroni-Bird, C. E., and Burns, L. D., (2010). *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*. Cambridge: The MIT Press.

Morganti, E., Seidel, S., Blanquart, C., Dablanc, L., and Lenz, B., (2014).The Impact of E-commerce on Final Deliveries: Alternative Parcel Delivery Services in France and Germany. *Transportation Research Procedia* [online]. **4**, 178-190. [Viewed 19 January 2019]. Available from: https://doi.org/10.1016/j.trpro.2014.11.014.

National Association of City Transportation Officials, (2019). *Don't Give Up at the Intersection: Designing All Ages and Abilities Bicycle Crossings* [online]. New York: National Association of City Transportation Officials (NACTO). [Viewed 21 January 2019]. Available from: https://nacto.org/wp-content/uploads/2019/05/NACTO_Dont-Give-Up-at-the-Intersection.pdf

Nancy, H., (2018).Nebraska tested driverless car technology 60 years ago [online]. *Journal Star*. [Viewed 30 January 2019]. Available from: https://journalstar.com/news/local/govt-and-politics/nebraska-tested-driverless-car-technology-years-ago/article_a702fab9-cac3-5a6e-a95c-9b597fdab078.html

National Association of City Transportation Officials, (2017). *Blueprint for Autonomous Urbanism* [online]. New York: National Association of City Transportation Officials (NACTO). [Viewed 25 January 2019]. Available from: https://nacto.org/wp-content/uploads/2017/11/BAU_Mod1_raster-sm.pdf

Ng, W., (2019). Four principles for the future of city streets [online]. *Side Walk Talk*. [Viewed 10 January 2019]. Available from: https://medium.com/sidewalk-talk/street-design-principles-fe35106e0f92

Ng, W., (2017). The next-generation intersection helps all modes share the street [online]. *Side Walk Labs*. [Viewed 2 April 2019]. Available from: https://www.sidewalklabs.com/blog/the-next-generation-intersection-helps-all-modes-share-the-street/

Niel, D., (2012). The driverless car is coming. And we all should be glad it is [online]. *Wall Street Journal*. [Viewed 17 January 2019]. Available from: https://www.wsj.com/articles/SB10000872396390443524904577651552635911824

Parsons, T., (2016). Android Auto vs Apple CarPlay [online]. *Stuff*. [Viewed 23 March 2019]. Available from: https://www.stuff.tv/features/android-auto-vs-apple-carplay

Paul, D., (2009). Bike-sharing: History, Impacts, Models of Provision, and Future [online]. *Journal of Public Transportation*. **12** (4): 41-56. [Viewed 15 March 2019]. Available from: DOI: http://doi.org/10.5038/2375-0901.12.4.3.

Peopleforbikes, (2014). The Green Lane Project's Style Guide [online]. *Peopleforbikes*. [Viewed 17 March 2019]. Available from: https://web.archive.org/web/20151025031814/http://www.peopleforbikes.org/green-lane-project/pages/the-green-lane-projects-style-guide#pbldefinition#pbldefinition

Rajamanickam, V., (2019). Today's Pickup: Tesla's new charging stations can charge cars in around 15 minutes [online]. *Freightwaves*. [Viewed 13 March 2019]. Available from: https://www.freightwaves.com/news/todays-pickup-teslas-new-charging-stations-can-charge-cars-in-around-15-minutes

Ridden, P., (2018). North America's first 200 kilowatt wireless charger keeps e-buses rolling indefinitely [online]. *New Atlas*. [Viewed 23 March 2019]. Available from: https://newatlas.com/momentum-200-kw-wireless-charging-transit-bus/54303/

Roe, W. and Toocheck, C., 2017. *Kerb Appeal: Kerbside Management Strategies for Improving Transit Reliability* [online]. New York: National Association of City Transportation Officials (NACTO). [Viewed 12 March 2019]. Available from: https://nacto.org/wp-content/uploads/2017/11/NACTO-Kerb-Appeal-Kerbside-Management.pdf

Roland Berger, (2018). *2018 nian quan qiu dian dong che fa zhan zhi shu* [2018 Global Electric Vehicle Development Index]. Beijing: Roland Berger.

Roland Berger, (2018). *Bike Sharing 5.0 Market insights and outlook*. Berlin: Roland Berger.

Shaheen, S. A., Guzman, S. and Zhang, H., (2010). Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future. *Transportation Research Record: Journal of the Transportation Research Board* [online]. **2143**, 159-167. [Viewed 1 May 2019]. Available from: DOI: 10.3141/2143-20

Shellenbarger, S., (2016). One Driver Can Prevent a Traffic Jam [online]. *The Wall Street Journal*. [Viewed 21 April 2019]. Available from: https://www.wsj.com/articles/one-driver-can-prevent-a-traffic-jam-1476204858

Sidewalk Labs, (2018). Draft Quayside Site Plan [online]. Toronto: Sidewalk Labs. [Viewed 2 January 2019]. Available from: https://www.sidewalktoronto.ca

Smartcitiesworld, (2017). 'Smart' intersection aims to increase safety [online]. *Smartcitiesworld.* [Viewed 14 March 2019]. Available from: https://www.smartcitiesworld.net/news/news/smart-intersection-aims-to-increase-safety-2422

Spek, S. C. V. D. and Scheltema, N., (2015). The importance of bicycle parking management. *Research in Transportation Business & Management* [online]. 15, 39-49. [Viewed 10 January 2019]. Available from: https://doi.org/10.1016/j.rtbm.2015.03.001.

Stanford, (2012). *London bike share* [digital image]. [Viewed 16 March 2019]. Available from: https://web.stanford.edu/group/suss/cgi-bin/main/blog/?attachment_id=4377

State of California - Department of Motor Vehicles, (2018). Autonomous Vehicle Disengagement Reports 2018 [online]. *State of California - Department of Motor Vehicles*. [Viewed 30 March 2019]. Available from: https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/disengagement_report_2018

Storyblocks, (2017). Head of electric car charging refueling station in Amsterdam city [online]. *Storyblocks*. [Viewed 15 April 2019]. Available from: https://www.videoblocks.com/video/netherlands-amsterdam-april-2017--head-of-electric-car-charging-refueling-station-in-amsterdam-city-bh0ff_trgjd14x7j4

Shuttleworth, J., (2019). SAE Standards News: J3016 automated-driving graphic update [online]. SAE International. [Viewed 6 January 2019]. Available from: https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic

Tachet R, Santi P, Sobolevsky S, Reyes- Castro LI, Frazzoli E, Helbing D, et al., (2016). Revisiting Street Intersections Using Slot-Based Systems. *Plos ONE* [online]. **11**(3): e0149607. [Viewed 5 January 2019]. Available from: doi:10.1371/ journal.pone.0149607

Teal, D., (2017). Daymak launches wireless charging on certain e-bikes [online]. *Autonomousvehicletech*. [Viewed 9 January 2019]. Available from: https://www.autonomousvehicletech.com/articles/90-daymak-launches-wireless-charging-on-certain-e-bikes

University of Michigan, (2017). Mcity Driverless Shuttle: A Case Study [online]. Michigan: University of Michigan. [Viewed 23 April 2019]. Available from: https://mcity.umich.edu/wp-content/uploads/2018/09/mcity-driverless-shuttle-case-study.pdf

U.S. Department of Labor Bureau of Labor Statistics, (2017). Consumer Expenditure Survey 2017 Microdata [online]. *Bureau of Labor Statistics*. [Viewed 15 January 2019]. Available from: http://www.bls.gov/cex.

Vega, N., (2017). Amazon wants to install delivery lockers in your apartment building [online]. *Aol*. [Viewed 21 March 2019]. Available from: https://www.aol.com/article/finance/2017/07/28/amazon-wants-to-install-delivery-lockers-in-your-apartment-build/23054513/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&-guce_referrer_sig=AQAAAHfnSrVrZQac9kxw75PkqIkvupkvJQvbLI3OgWha0qxcQIoIWz-NbKot34TuRxvDFaaS-UsXujGhP2L8n7WLWOQF3_dNVjrkDTX2zLtGRZ1fg4j9tf9NZ15_e9T-91KxEcKF0GbI4LrApbdebHXhFjXd3yYvbu-QHdJKLVx5Zdr_dL

Waes A. V., Farla, J., Frenken, K., Jong, J. P. J. D., and Raven, R., (2018). Business model innovation and socio-technical transitions: A new prospective framework with an application to bike sharing. *Journal of Cleaner Production* [online]. **195**,1300-1312. [Viewed 10 January 2019]. Available from: https://doi.org/10.1016/j.jclepro.2018.05.223.

Walker, J., (2019). The Self-Driving Car Timeline – Predictions from the Top 11 Global Automakers [online]. *EMERJ*. [Viewed 10 March 2019]. Available from: https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/

Wei, T. T., (2019). NTU and Volvo launch world's first full-sized driverless electric bus for trial [online]. *Straitstimes*. [Viewed 9 March 2019]. Available from: https://www.straitstimes.com/singapore/transport/ntu-and-volvo-launch-worlds-first-full-sized-autonomous-electric-bus-for-trial

Willkins, J., (2016). All aboard the driverless bus: is automated public transport on the way? [online]. *Engineers Journal*. [Viewed 6 January 2019]. Available from: http://www.engineersjournal.ie/2016/11/29/driverless-automated-metro-bus/

Wu, G., (2018). Chinese Economic Strategies Have Arrived at the Intersection [online]. *Ftchinese*. [Viewed 7 March 2019]. Available from: http://www.ftchinese.com/story/001078755?full=y&archive

Ye, L. and Yamamoto, T., (2018). Impact of dedicated lanes for connected and autonomous vehicle on traffic flow throughput. *Physica A: Statistical Mechanics and its Applications* [online]. **512**, 588-597. [Viewed 2 April 2019]. Available from: https://doi.org/10.1016/j.physa.2018.08.083.

Zhao G. R., (2018). *E-commerce in China 2018*. Beijing: China Commerce and Trade Press.

Appendices

Appendix 1: History of Autonomous Vehicles

1950s	Initial trials began
1977	The first truly automated car
1980s	Autonomous prototype cars appeared
1990s	Semi-autonomous cars such as VaMP, Vita-2 and ParkShuttle were tested on roads.
1991	The United States Congress passed the ISTEA Transportation Authorization bill to license the demonstration of AVs .
2004	The first Grand Challenge was held
2008	The first commercial autonomous mining haulage system
2009	Google started its self-driving cars
2013	Many major automotive manufacturers began their tests of driver-less systems
2014	Tesla announced its first version of AutoPilot.
2016	The first self-driving taxi service appeared in Singapore
2018	The first fatal crash involving a self-driving vehicle happened

Appendix 2: J3016 Levels of Automated Driving graphic

Appendix 3: Comparison of mainstream autonomous vehicles

System	SAE Level	Kilometers per Disengagement	Power Source	Application Condition
Waymo	Level 4	17,856.8	Electric Mainly	Over 5 millon road miles test completed. Formal service was launched at the end of 2018
BMW	Level 4	7.3	Electric	2021 is the estimated time of autonomy
Zoox	Level 3	3076.4	Hybrid	2020 is the estimated time of autonomy and ready for passengers
Renault-Nissan Alliance	Level 3	336.8	Hybrid	2020 is the estimated time of autonomy
Daimler	Level 3	2.3	Electric	2020 is the estimated time of autonomy
Volkswagen	Level 2 +	Semi-Autonomous	Hybrid	2021 is the estimated time of autonomy
Tesla	Level 2	Semi-Autonomous	Electric	2020 is the estimated time of autonomy
GM Cruise	Level 2	8327.8	Electric	2019 is the estimated time of autonomy
Toyota	Level 2	4.1	Electric	2020 is the estimated time of autonomy
Ford	Level 2	Semi-Autonomous	Hybrid	2021 is the estimated time of autonomy
Volve	Level 2	Semi-Autonomous	Hybrid	2021 is the estimated time of autonomy
Baidu	Level 2	329.0	Petrol	2021 is the estimated time of autonomy
Uber	Unknown	0.6	Hybrid	Unclear

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