# *Green Travel & Clean Air in Zhengzhou*

**MIT Sustainable Urbanization Practicum**

MIT School of Architecture and Planning
Department of Urban Studies and Planning
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# Introduction

Air pollution and traffic congestion have become major threats to the quality of life in many cities in the developing world. In recent years, Chinese central and city governments have been taking actions on various green transportation initiatives. Public and private companies as well as academia are also engaged in this endeavor. All are involved in devising technologies, economic and policy frameworks to support inclusive, and innovative and sustainable transportation projects. However, often the interests, goals, and timeframes of these stakeholders are not aligned.

In the practicum of "Sustainable Urbanization Pilot 2020: Green Travel and Clean Air in Zhengzhou" , the MIT Sustainable Urbanization Laboratory (MIT-SUL) partnered with governmental agencies and companies in Zhengzhou (Henan Province, China) to conduct a semester-long course that combined fieldwork, active participation of multiple stakeholders, and research. This Policy Guideline presents the results of this practicum. By bridging the gap between the academic and the professional worlds, we offer a combination of academic research grounded on real-world issues, with the common goal of achieving sustainable urbanization.

In 2001, Zhengzhou, the capital city of the Henan province, started the construction of Zhengdong New District—a 150-square-kilometer mixed-use area home to 320 financial institutions, 29 universities, a broad array of information and service industries, a high-speed rail station, and 1.5 million inhabitants. Zhengdong New District is divided into six functional regions, including Central Business District (CBD), Commercial Logistic District, Dragon Lake District, Longzihu District, Science and Technology Park District, and Economy and Technology Development District. As one of the pioneers in China's new cities movement, Zhengdong New District is proud of its increasing economic competitiveness, vibrant public spaces, agreeable environment, and enhanced quality of life. Zhengdong is one of China's first new cities planned with comprehensive urban functions. It is also a pioneering new city that has incorporated ideologies of internationally renowned designers.

During this rapid urban expansion, air pollution and road congestion remain prominent issues. Air pollution in Zhengzhou has PM2.5 as the primary pollutant, and it is especially severe in winter due to the reliance on coal and other meteorological conditions. Average PM2.5 levels during this time can be higher than 120 μg/m3, with the hourly maximum sometimes hitting 400 μg/m3—for reference, the WHO suggests an hourly PM2.5 level less than 25 μg/m3, citing the abundance of human health concerns (such as asthma, respiratory infection, stress, and high mortality rates) that can be observed when these levels are surpassing. According to a randomized survey with 3230 local residents, conducted by MIT-SUL in the summer of 2019, 83.53% of respondents think the local air quality in Zhengdong in winter is bad or terrible. More than 99% of residents think air pollution in Zhengzhou impacts their health, among which, 73.48% views the impacts as large or severe.
After accounting for buildings, transportation is one of the key polluters in urban areas, and Zhengzhou is investing in vehicular use restrictions as well as in public transportation. A key partner in these efforts is Yutong, a Chinese automotive company which is the largest manufacturer of electric buses in the world, and has implemented electric self-driving buses on the "Intelligent Island", in the Longzi Lake area of Zhengdong. The system has been in operation since June 2019, and future phases include the implementation of the first Bus Rapid Transit (BRT) corridor in the world based on autonomous buses.

The combination of a critical issue in urban environments (air quality), with a government committed to find solutions towards green transportation, and companies innovating at the global scale, brings an exciting challenge to MIT students: how to advance knowledge and, at the same time, turn gathered and synthesized data into guidelines and recommendations that can be used to guide public and private processes dealing with green transportation and sustainable urban development goals in Zhengzhou.

In response, MIT's Sustainable Urbanization Lab brought 10 students led by the teaching team to Zhengzhou, China, in order to conduct fieldwork and acclimate themselves in the planning context of the city by meeting with different companies and government agencies tackling urban planning challenges. For 10 days during January of 2020, students met with local development firms, transit agencies, and government sponsors to identify some of the specific problems each entity was striving to resolve. Among the several topics we proposed together with the stakeholders, we selected three topics we deemed as the most impactful. Each would have effects in the short, medium, and long terms along Zhengzhou's urbanization path: autonomous buses, transit oriented development, and air quality sensing.

Autonomous vehicles may lead to safer and less congested roads thus contributing to sustainable transportation plans. Building on already existing technology deployed in Zhengzhou, in the section Autonomous buses in Zhengzhou, we present what other few companies in the world are doing to implement autonomous buses. More importantly, we interviewed more than 500 inhabitants in Zhengzhou, and 41% of them have already used the autonomous buses. Most of them have a highly positive view of the system and would be willing to use the autonomous BRT. We complement the survey with international case studies. In this section, we propose a policy framework that can not only make the autonomous BRT in Zhengzhou stronger but also be used as a template to foster the implementation of this technology in other cities in China and abroad.

Zhengzhou, among the ten fastest-growing cities in China, has been investing intensively on its subway system, remarkably establishing a network of five lines and 142 kilometers in the past six years. In addition to providing the pure transit benefits to the city the government, real estate developers, and subway operators, are trying to devise ways to capitalize, and later distribute, the benefits of the subway system across multiple social and economic stakeholders. To achieve this goal, these groups work with Yasin Holdings, to employ Transit-Oriented Development (TOD) strategies using mass transportation systems as the backbone of urban development. The strategy uses the economic success of these real estate developments to boost the same area, improving transit and active modes through a multi-model network, including pedestrian and bicycle infrastructure, and in the case of Zhengzhou, autonomous buses. In the section Creating a Livable City through Transit Oriented Development we analyze case studies from different countries, and propose a framework that can be used to guide Zhengzhou developers through TOD strategies informed by global best practice, in different areas of the city with the goals integrating environmental and economic sustainable urban developments, focused on creating a more inclusive city.

Understanding the micro-level air pollution exposure is essential for informing citizens about their air pollution risk, thus getting people better educated for self-protection choices. In the section Smart Sensing and Green Travel, we worked with Yutong Bus to propose the use of low-cost portable monitoring devices to be initially implemented in autonomous buses running in the Intelligent Island to measure ambient air quality. Through an extensive survey on local residents, we have identified strong awareness of air pollution, a pressing need for self-protection from pollution, and willingness to use vehicular transport to avoid pollution among citizens in Zhengzhou. We also formulate design concepts that transform the current interfaces at buses and bus kiosks into more engaging and informative ones that deliver air quality information intuitively and promote self-protection actions. By streaming this data to an online platform, the goal is to optimize the monitoring network for better understanding the real-time human air pollution exposure.

This report provides a practical and evidence-based strategy for Zhengzhou's sustainable urbanization in three key areas: Autonomous Buses (AV Bus), Sensing, and Transit-Oriented Development (TOD), with the objective of informing their policy designs of green transportation development in the next decade. Underlying the three sections, there is a long term integral vision of how technology and behavioral science could be integrated into urban transportation planning. The report has an ambitious goal to make real-world differences in improving the environmental quality and overall well-being of Zhengzhou.

We are grateful to the support of Zhengzhou Zhengdong New District Administrative Committee, Zhengzhou Yutong Bus Co., Ltd., Yasin Holdings, Operations Office of Zhengzhou Bus Communication Corporation (ZZB), the Public-Private Partnership Research Center (in School of Naval Architecture, Civil and Ocean Engineering) at Shanghai Jiao Tong University (SJTU), and the Department of Urban Studies and Planning (MIT) in our research and teaching. We also thank Wei Ningdi (Zhengdong New District Administrative Committee); Ren Yongli (Yutong), Xu Ti (Yutong), Gu Chaoran (Yutong); Zhang Yongliang (Yasin), Zhang Chuanye (Yasin), Wang Chen (Yasin); Dai Lei (SJTU), Huang Yujie (SJTU), Qi Changlu (SJTU), Guo Yuanyuan (ZZB), Niu Dongxiao (Tsinghua and MIT), and Zhai Guochen (MIT), for their helpful comments and suggestions.

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## Chapter 1.

# *Autonomous Buses in Zhengzhou: Informing Policy with Citizen Interviews and International Comparisons*

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# Introduction

Zhengzhou is China's national transportation hub. As one of the country's "Bus Cities", it has invested heavily in urban transit leadership. After a successful city bus electrification initiative completed earlier this decade, the city leadership is now accelerating development of autonomous bus (AB) technology. In 2019, Zhengzhou joined the small group of cities that have hosted an AB pilot project, and the city is moving quickly and deliberately to integrate true autonomous routes into its existing bus system. The city benefits from a close cooperation with Yutong, the bus manufacturing giant that is headquartered in Zhengzhou. Together, Yutong and Zhengzhou have the opportunity to become global leaders in the development of autonomous bus technology.

In order to help realize the city's goals, MIT undertook a thorough review of the city's existing AB projects and the local conditions that could help AB technology flourish. Through conversations with government administrators in Zhengzhou and technology managers at Yutong, we came to understand the ambitions they have for their city: to become a world leader in connected, intelligent, and green technology, and the possessor of a brain-driven, services-first economic model. MIT's challenge is to lend an outside and international perspective on the process of attaining that future. With national backing, Yutong's technology, and a population that overwhelmingly supports this investment, we believe that Zhengzhou can reach this future.

This chapter reports our research, findings, and recommendations for Zhengzhou and Yutong. In the first three sections, "Background," "Literature Review," and "Case Studies," we provide context for autonomous bus policy, the implementation process in Zhengzhou, and how the city can drive forward this new transportation technology. Next, we review the original research we performed for this chapter: stakeholder interviews and a citizen survey in Zhengzhou. In the final section, we present recommendations for the Zhengzhou municipal government and for the Yutong Bus Company.

**Table 1.** SAE Vehicle Automation Levels, extracted from Greenblat & Shaheen, 2015.

| Level | Automation Type | Description |
|---|---|---|
| 0 | Driver Only | No automation |
| 1 | Assisted | Autonomy of one primary control function, e.g. adaptive cruise control, self parking, lane keeping assist or automated braking |
| 2 | Partial Automation | Autonomy of two or more primary control functions "designed to work in unison to relieve the driver of control of those functions" |
| 3 | Conditional Automation | Limited self-driving; driver may "cede full control of all safety critical functions under certain traffic or environmental conditions," but it is "expected to be available for occasional control" with adequate warning |
| 4 | High Automation | Full self-driving; driver "is not expected to be available for control at any time during the trip" (includes unoccupied vehicles) |
| 5 | Full Automation | Full self-driving without human controls |

Source: SAE International, 2016

# Background

Cities around the world are increasingly testing autonomous bus (AB) technology at various implementation levels. The Society of Automotive Engineers recognizes five levels of autonomy, shown in Table 1. “Full automation” has yet to be implemented on public roads anywhere.

Cities are still learning how to integrate AB technology into their transportation systems to accomplish the traditional transit goals of reduced operating cost, increased customer comfort and safety, and increased ridership. Zhengzhou has a demonstration project already in operation, the “Intelligent Island Pilot”, has initiated a bus rapid transit project, the “East Third Ring Road BRT”, and is planning an additional BRT, the “Financial Island BRT”. These projects are described in detail below.

*Intelligent Island Pilot*

The Zhengzhou Municipal Transportation Bureau and the Yutong Bus Company launched a Level 4 autonomous bus pilot project on the city’s Intelligent Island in May 2019. The pilot includes four 5-meter electric shuttles with capacity for half a dozen passengers that can reach speeds of up to 12 mph. The buses circuit a one mile loop around the island on a public road, interacting with seven traffic lights and three bus stops. By January 2020, the shuttles had carried more than 10,000 passengers. The goals of this pilot are to test the technology and enable Zhengzhou citizens to experience ABs.

*East Third Ring Road BRT*

If completed on schedule, the East Third Ring Road BRT project would be one of the first autonomous BRT projects in the world. This project, like the Intelligent Island Pilot, is a partnership between the Zhengzhou Municipal Government and the Yutong Bus Company. For this project, Yutong is providing close to a turnkey solution for the Zhengzhou Municipal Transportation Bureau, managing the design, maintenance, product manufacturing, software, and operations stages. For the currently operating municipal bus fleet, these responsibilities are managed by the Zhengzhou Municipal Bus Company, which is a joint public-private entity. Because of the experimental and techno-centric nature of this project, Yutong is taking increased responsibility.

The project will use 12-meter buses with Level 3 autonomy, which means there will be a driver in the vehicle who can take control when necessary. The BRT will trace the East Third Ring Road, connecting the Zhengdong New District to the old city center. This route already existed in the master plan for the future bus system in Zhengzhou before it was approved to host AB technology. Zhengzhou has already initiated this project and tendered parts of its operation. The new service was planned to start operating in October 2020. This schedule will likely be delayed due to the ongoing global pandemic of COVID-19, which has disrupted development in Zhengzhou and throughout the world.

*Financial Island BRT*

Another BRT project that is in planning stages in Zhengzhou is the Financial Island BRT project. Similar to the East Third Ring Road BRT project, the operation and production for this project will not be taken on by the government. In this case, Yutong will be splitting the provision of autonomous buses with Baidu, which is also developing AB technology. These will also be 12-meter buses with Level 3 autonomy, and will circulate around the Financial Island. Launch of this project is planned in 2020.

Zhengzhou's AB Bus

# Literature Review

## Introduction

Although the academic and professional literature surrounding autonomous vehicles (AVs) is extensive (Nascimento et al. 2019), literature focusing specifically on autonomous buses (ABs) has only recently begun to accumulate. To understand existing work that applies to ABs in the City of Zhengzhou and to Yutong, we built off a recent literature review conducted by Azad et al. (2019) that surveyed 40 English-language articles published after 2010. We added 10 additional articles that have been published since Azad et al.'s work, extending the review's geographic footprint into Asia. We group the articles into five general categories: Economic Impact, Public Policy, Safety, Technology, and User Acceptance. The distribution of articles is shown in Figure 1.

According to conversations with project stakeholders in Zhengzhou, we identified three special areas of interest:
1. *Incremental value offered by ABs due to integration in existing transit systems,*
2. *Roles for AB supervisors or attendants,* and
3. *Safety performance and perceptions by riders.*

We focus the remainder of the literature review on these topics.

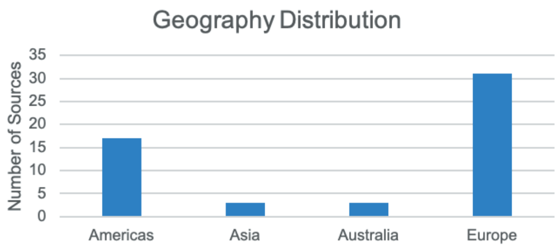
## Incremental Value to Transit System

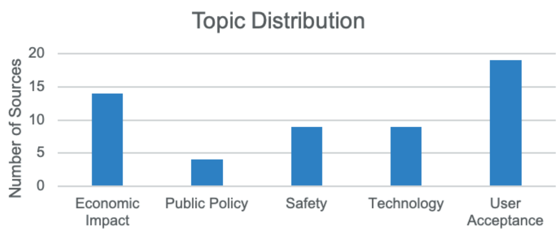
Labor cost reductions from the elimination of the bus driver is the largest economic impact of ABs for transit providers. The labor share of operating expenses ranges from about 45% (in Texas, from Quarles and Kockelman 2018) to 70% (in Zhengzhou, according to conversations with government officials). Though bus attendants or remote human operators may be necessary in ABs for the near future, many sources expect them to be needed in smaller numbers than drivers currently are (Quarles and Kockelman 2018, Abe 2019).

Research also points to smoother driving of autonomous buses as a result of computer optimized driving mechanics, which can significantly reduce fuel consumption (Liu et al 2017). Lower fuel consumption also implies fewer emissions and improved air quality. Smoother driving can also increase people's comfort level when riding the bus (Quarles and Kockelman 2018).

Despite the operational efficiencies, upfront costs from AB acquisition are higher than for traditional buses because of the additional cost of sensor hardware and driving software. Although estimates of these capital costs are wide-ranging, the literature generally agrees that they will be small compared to driver cost savings (Quarles and Kockelman 2018).

**Figure 1.** We illustrate the distribution of articles in our literature review by year of publication (left) and by policy topic (right).



Most of the literature approaches the economic impacts of ABs using a cost-benefit analysis framework (Abe, 2019; Bosch, et al., 2018, Quarles and Kockelman 2018). Some research uses numerical simulation to estimate the performance of the autonomous buses and evaluate their influences on the transit system. For example, Bosch, et al. (2017) adopt an agent-based transportation model to evaluate various transportation policies under the new AB scenario.

## Role for Autonomous Bus Supervisors

As AB projects worldwide approach full autonomy, researchers are exploring the roles of onboard attendants or supervisors. Dong et al (2017) found that two-thirds of survey respondents were willing to ride in an AB provided that there was a transit employee onboard to monitor vehicle operations and provide customer service. They found only 13% would ride without an employee on board. Females and seniors are more concerned about riding without an employee on board. Piao et al (2016) similarly found attendants to be important to users due to concerns of personal security, particularly at night.

Azad et al (2019) noted that although many studies have found user perceptions to be significantly improved by the presence of a transit employee on board, more research needs to be done in this area. Riders accustomed to automation may no longer need an attendant on board, especially on routes and at times when buses are likely to be full, reducing concern over security from other passengers. Virtual attendants may be able to fill the role of monitoring passengers remotely via video. Salonen (2018) has suggested replacing an attendant with a vendor or other service provider onboard.

## Safety Performance and Perceptions

Existing literature covering the topic of safety in autonomous bus systems can broadly be split into measurement of actual safety performance and user perceptions of performance. Much of the safety literature for ABs overlaps with literature concerning AVs in general. In this section, the term “safety” refers only to traffic accidents; on-board crime is termed “security”.

We found no literature that studied actual safety performance of ABs, either in absolute terms or relative to traditional buses. This is related to the fact that ABs have had limited vehicle-miles in realistic traffic conditions, though there have been documented traffic accidents. Notably, a manned delivery truck backed into a Las Vegas, USA AB pilot in 2017 (Gibbs 2017), and an AB pilot collided with a pedestrian in Vienna, Austria in 2019 (Porter 2019). One thread of research sidesteps the problem of absent data by studying the safety record of traditional buses, illustrating the room for improvement (Lutin et al. 2016). Other studies recommend that safety-enhancing innovations from the passenger car industry be adapted for future bus systems (Xiao et al. 2020). This may be an interesting path for Yutong to consider, as ABs will be redesigned anyway. As ABs mature, we expect more literature studying actual safety performance to emerge.

The literature surrounding perceptions of safety is much richer. Most AB specific articles deploy stated-preference surveys of either potential AB passengers or participants in AB pilot programs. The results from these surveys indicate that the public views ABs as safer than traditional buses (Salonen 2018, Portouli et al. 2017). The applicable research from the general AV literature takes a psychological perspective. Shariff et al. (2017) suggest that governments clearly communicate the absolute safety benefits to the public while acknowledging there will still likely be traffic accidents, and also that they proactively define liability policies. Large international surveys have also shown some variation in perceptions of safety. For example, Moody et al. (2020) find that perceptions are more positive in Asia than in Western Europe. Interpretation of our international case studies takes this into account.

# International Case Studies

To complement our research in Zhengzhou, we undertook three international case studies to better understand the interaction between AB policies and transit outcomes. In choosing our case studies, we strove to encompass not just diverse geographies, but also different project focuses. Accordingly, we studied one project in the USA, "SMART Columbus," that focused on urban mobility with mini-buses. We spoke with a team in Scotland planning full-size AB transportation between cities in "Project CAV Forth." We also interviewed a team in Switzerland exploring urban Mobility-as-a-Service in the "Swiss Transit Lab: Route 12" project. Below we detail our findings from these interviews.

## SMART Columbus

*Key Takeaways*

The goal of the SMART Columbus project goes beyond demonstrating and testing autonomous technology. The city is using the AB project to connect the low income neighborhood of Linden to the main transit network, and to recreation and community service destinations. The bus attendants are also Linden residents, offering well-paying jobs to residents of the neighborhood that is serving as the testing ground (Ferenchick, 2020). This combination of social and technological initiatives integrates traditionally disparate urban goals and brings wider support to AB projects. Working toward a goal beyond development and testing of technology also helped the City to secure funding from USDOT and from philanthropy.

| | |
|---|---|
| **Location** | Columbus, Ohio, USA |
| **Start Date** | February 5, 2020 |
| **Vehicles** | 12 electric passenger vans, Level 4 |
| **Route** | 2.9 miles, 4 stops, connecting to larger transit system from low income neighborhood |
| **Schedule** | 6 AM to 8 PM, 12 minute frequency at peak |
| **Maximum Speed** | Maximum 25 mph, average 12-18 mph |
| **Funding** | $40M - USDOT's Smart Cities Challenge<br>$10M - Paul G Allen Philanthropies |
| **Private Sector Partners** | EasyMile<br>Empower Bus |

**Table 2.** A description of the SMART Columbus project. Source: (Ferenchik, 2020; Wanek-Libman, 2020; Smart Columbus, 2020)

## Project CAVForth

*Key Takeaways*

Stagecoach East Scotland and Edinburgh Napier University hosted a "Design Jam" that engaged residents in the design of the ABs, even compensating them for their participation. This user-centric design practice is likely to improve outcomes for users. It also will likely improve perceptions of safety and public acceptance generally (Lawrie, 2019).

Transport Scotland is launching this project following the creation of the Connected and Autonomous Vehicle (CAV) Roadmap, which lays out a vision for how the agency will engage with this new technology in order to be a leader in deployment, and to accomplish public goals. This comprehensive vision was also aligned with other transportation and regional plans, considering the next 20 years. This visioning has likely kept partners on the CAVForth project aligned and coordinated, and ensured decisions are made toward long term development and public goals (Transport Scotland, 2020b).

| | |
|---|---|
| **Location** | Interregional, Scotland |
| **Start Date** | Pending, second half of 2020; public demo on March 18, 2019 |
| **Vehicles** | 5 non-electric single decker 42-passenger buses, Level 4 |
| **Route** | 14-mile route between Fife and Edinburgh |
| **Schedule** | Approximately 47 trips per bus per week, TBD |
| **Maximum Speed** | Maximum 50 mph |
| **Funding** | $7.63M - Centre for Connected and Autonomous Vehicles (CCAV) and UK Government's Intelligent Mobility Fund |
| **Private Sector Partners** | Fusion Processing Ltd<br>Alexander Dennis Ltd<br>Stagecoach Group plc |

**Table 3.** A description of Project CAV Forth. Source: (Transport Scotland, 2020a; Stagecoach, 2019)

| | |
|---|---|
| **Location** | Schaffhausen, Switzerland |
| **Start Date** | March 2018 |
| **Vehicles** | 1 electric 11-seat shuttle buses, Level 3 |
| **Route**<br>**Schedule** | 0.75-mile route, 7 stops, between Neuhausen am Rheinfall station and Rhine Falls Basin |
| **Maximum Speed** | Monday - Saturday 1 pm to 5 pm; Sundays and holidays 10 am to 6 pm |
| **Funding** | Maximum 18.5 mph, average 9.5 mph |
| | $1.03M - Regional Development of Economic Promotion canton of Schaffhausen |
| **Private Sector Partners** | Swiss Transit Lab - P3<br>Trapeze<br>AMoTech<br>p2data GmbH<br>PhotoGnosis GmbH<br>NAVYA |

**Table 4.** A description of the Swiss Transit Lab project. Source: (Buezberger, 2020; Swiss Transit Lab Press Release, 2019; SPACe, 2020)

## Swiss Transit Lab: Route 12

*Key Takeaways*

There were multiple goals for this project, including integrating autonomous vehicles into the existing public transport system, advancing the autonomous bus technology including mobility-as-a-service applications, and increasing the acceptance of AV among the public (Wicki and Bernauer, 2018, Swiss Transit Lab, 2018). The organized and transparent governance process that has guided project development and operation is a key factor for success. There is a clear chain of accountability for outcomes from the public to the decision-makers. The public participated in three survey waves administered by the regional transportation agency, which leads the project implementation. Those results are reported to the national government, which provides important policy and financial support subject to success. Documents from each stage of this chain are publicly accessible, which increases accountability and likely improves outcomes.

# Methods

In this section we detail the procedures used in conducting the two distinct researches of this Chapter: the User Survey and the Interviews

## User survey

We conducted a survey of 516 Zhengzhou residents during March and April of 2020 using Wenjuanxing/问卷星, the Chinese online survey tool. The survey consisted of several dozen questions and was designed to take around 10 minutes to complete. We used the "guaranteed response" feature from Wenjuanxing/问卷星 to delegate the task of soliciting responses using advertising or other outreach methods.

The survey questions ask about respondents' perceptions of the Smart Island Pilot project, the 3rd East Ring Road BRT project, and Zhengzhou AB development in general. We also included detailed questions about user satisfaction, and the reasons they would or would not take the autonomous bus. Further we asked questions concerning sociodemographics and their mobility behaviour, and asked for suggestions on Zhengzhou AB policies. Due to the highly structured nature of the survey responses we were able to rely on the results dashboard in Wenjuanxing/问卷星 to analyze and export our findings.

## Interviews

We conducted a series of semi-structured interviews of key stakeholders in order to understand the AB policy and implementation landscape in Zhengzhou. We were specifically interested in the roles, alignments, and perceptions of these stakeholders to complement the user survey data that we had collected and the international comparators that we studied.

### *Interviewee Selection*

We first mapped out the stakeholders that are involved in the planning and implementation of the AB projects in Zhengzhou. From this list we reached out to stakeholders we had connections with through MIT and the project sponsors. We were able to interview representatives from four organizations, shown in Table 5. The COVID-19 pandemic constrained our ability to connect with many of these officials whose work and lives were disrupted.

| | |
|---|---|
| **Interviewed** | Henan Provincial Government<br>Zhengzhou Municipal Transportation Bureau<br>Zhengzhou Municipal Bus Company<br>Yutong Bus Company |
| **Not Interviewed** | Chinese Central Government<br>Zhengzhou Municipal Government<br>Baidu AB Team<br>East District Administrative Committee |

**Table 5.** Stakeholder organizations

### *Interview Design*

We based our interview design on the practical guide assembled by Schmeer (1999) for use by Harvard University and USAID, which itself was constructed after an extensive literature review. The two principles driving our interview design were (1) consistency across interviews, such that responses from multiple sources could be meaningfully compared, and (2) the collection of both structured (quantitative) and unstructured (qualitative) data to enable two complementary modes of analysis.

To the extent possible, we asked interview respondents to provide feedback on four projects: the AB Pilot Project, the East Third Ring Road Project, the Financial Island Project, and the completed Zhengzhou transit electrification project.

The interviews were conducted virtually in Chinese and translated to English for the purposes of this report.

*Structured Component*

The structured questions we posed sought to understand the extent to which stakeholder organizations (1) were aligned to each other, (2) viewed various aspects of the relevant projects, and (3) prioritized different aspects of the AB projects. We distributed templates using the standard subjective ranking format from "1 (low)" to "5 (high)".

The *Stakeholder Alignments* set asked each respondent to assign rankings according to how well he/she perceived all stakeholder organizations were aligned for a specific project. Figure 2 shows the template that we distributed.

The *Stakeholder Perceptions* set asked each respondent to assign rankings according to how he/she perceived each stakeholder organization to view the various projects. We investigated three variables: familiarity with the project, interest in the project, and resources allocated to the project. Figure 3 shows the template that we distributed

The *Stakeholder Priorities* set asked each respondent to rank how he/she perceived the goals of a specific project. We investigated a range of possible goals that we extracted from the literature. Figure 5 shows the template we distributed.

*Unstructured Component*

The unstructured, or free-response, portion of our interviews were conducted in a traditional live format. We let each respondent drive the conversation forward, so that we minimally influenced their responses through framing effects. We also distributed questionnaires asking for written answers to specific questions. Based on the research of Schmeer (1999), we covered a deliberate set of topics in the interviews, which together define a complete stakeholder landscape. These topics are: Economic Development, Green Travel, Increased Transit Ridership, Convenience, Safety, Equity, Technology Innovation, and Transportation Efficiency.

| **Level** | ZMG | ZEDMC | ZEMTB | ZMBC | YB | ZC | ZBD |
|---|---|---|---|---|---|---|---|
| ZMG | | | | | | | |
| ZEDMC | | | | | | | |
| ZEMTB | | | | | | | |
| ZMBC | | | | | | | |
| YB | | | | | | | |
| ZC | | | | | | | |
| ZBD | | | | | | | |

ZMG: Zhengzhou Municipal Government
ZEDMC: Zhengzhou Eastern District Management Committee
ZEMTB: Zhengzhou Municipal Transportation Bureau
ZMBC: Zhengzhou Municipal Bus Company
YB: Yutong Bus
ZC: Zhengzhou Citizens
ZBD: Zhengzhou Bus Drivers

**Figure 2.** Stakeholder Alignments - Table

| **Familiarity** | AV Bus Pilot | AV BRT: East Ring Road | AV BRT: Financial Island |
|---|---|---|---|
| ZMG | | | |
| ZEDMC | | | |
| ZEMTB | | | |
| ZMBC | | | |
| YB | | | |
| ZC | | | |
| ZBD | | | |
| BMG | | | |
| GB | | | |

ZMG: Zhengzhou Municipal Government
ZEDMC: Zhengzhou Eastern District Management Committee
ZEMTB: Zhengzhou Municipal Transportation Bureau
ZMBC: Zhengzhou Municipal Bus Company
YB: Yutong Bus
ZC: Zhengzhou Citizens
ZBD: Zhengzhou Bus Drivers
BMG: Boston Municipal Government
GB: Google Bus (Waymo)

**Figure 3.** Stakeholder Perceptions - Table

We also asked the interviewees a set of qualitative and quantitative questions related to the AB programs. These covered the local advantages in AV Bus development, decarbonization impact, and safety. These topics were selected after preliminary stakeholder interviews in Zhengzhou revealed them to be of special interest to our clients and sponsors.

## Interview Analysis

After conducting the interviews, we prepared the written responses, both structured and unstructured, for further analysis. The structured data we validated and loaded into a relational database. We conducted exploratory data analysis in R to develop an understanding of the variation, means, and trends in the interview responses. For the unstructured data, the responses were coded based on key themes and concepts, allowing for comparison across answers.

| | |
|---|---|
| Knowledge of Policy<br>Definition of Policy<br>Position on Policy - Self-Reported<br>Position on Policy - Other-Reported<br>Interest in Policy | Stakeholder alignment<br>Leadership Level<br>Resource Quantity<br>Resource Control |

**Table 6.** The set of interview topics.

The results from the AB section of the interviews were compared to the results from the EV bus section to identify lessons learned that could be adapted for the AB projects.

# User Survey Results

## Smart Island Autonomous Bus Pilot Project

Figure 6 shows the proportions of the respondents that have taken autonomous buses before. About 41% of the respondents said they have, with 29% reporting having taken the Smart Island Autonomous Bus in the past. 60% have never taken autonomous buses before. Figure 7 details the divide by the neighborhoods that the respondents live in, from which we can tell that individuals in Jinshui District have the highest proportion of people having taken the bus, whereas Huiji District sees the lowest proportion.

For those who have taken the Smart Island Autonomous bus, the survey results show that they generally give positive feedback. According to Figure 6, the majority agree with the statements that they would like to take the Smart Island autonomous bus again and that they would like to recommend the Smart Island autonomous bus to others.

Figure 7 presents people's satisfaction levels for aspects of the Smart Island Autonomous Bus project. The results shows that the respondents have the highest satisfaction in terms of the access to the bus stop, the comfort level at the bus stop, and the experience of the new technology. Time interval between buses and the coverage of AV scenarios had the lowest satisfaction levels. However, the general satisfaction with the autonomous bus project is very high.

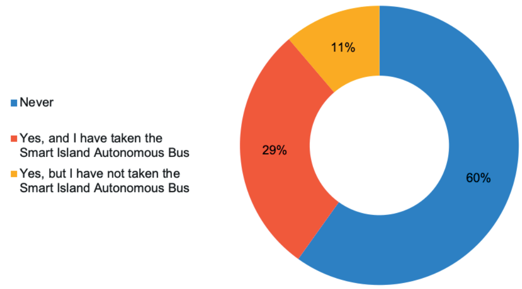



**Figure 4.** Responses to *Whether you have taken autonomous buses before?*

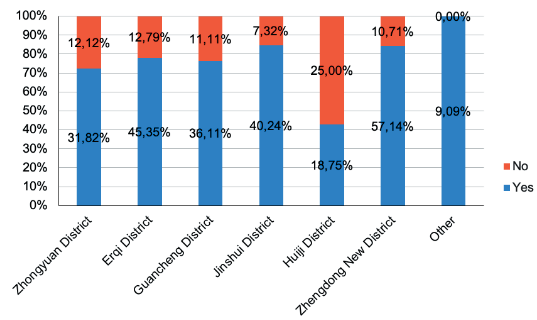



**Figure 5.** Responses to *Whether you have taken autonomous buses before?* by neighborhood

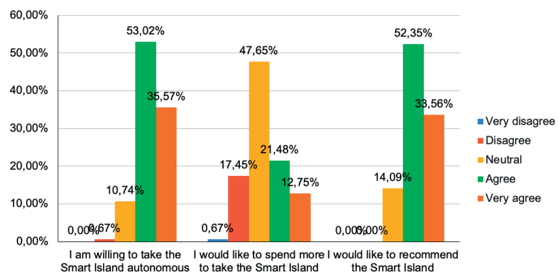



**Figure 6.** People's attitudes towards the Smart Island Autonomous Bus project in general

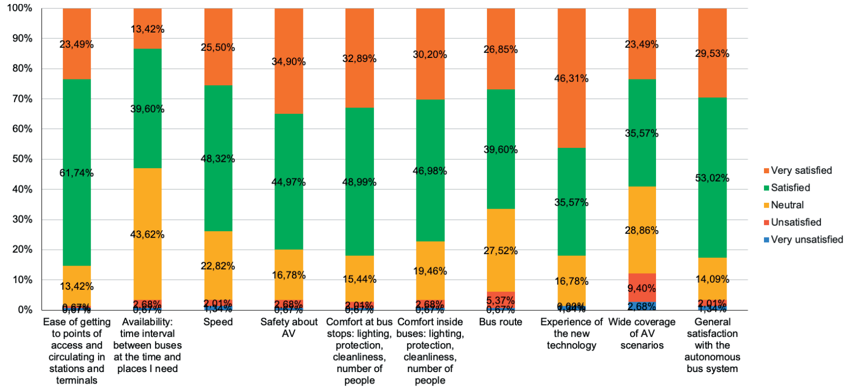



**Figure 7.** People's satisfaction level towards the Smart Island Autonomous Bus project regarding various attributes

## 3rd East Ring Road Autonomous BRT Project

Figure 8 shows whether the participants are willing to take the autonomous buses after the comprehensive introduction of autonomous buses. The results show that most respondents (95.54%) are willing to take the 3rd East Ring road ABRT when it becomes available. The majority of the respondents show a high willingness to take an AB if it operates on the route they normally take. Lastly, we pose that there is no bus attendant present. In this case, only 30.81% of the respondents said they would still be willing to take the bus.

Figure 9 shows the reasons people are willing to take the bus.'Experience autonomy technology' wins the highest votes, with 86% of the respondents agreeing. In contrast, only 28.4% said they want to take the bus because it is safer, which again reveals the potential safety concern.

## General Thoughts About Zhengzhou Autonomous Buses

Figure 10 shows people's attitudes towards the AB efforts in Zhengzhou. Among all respondents, 86.82% said they would rather the transportation bureau spend effort on ABs compared with traditional bus service. 98.26% regarded it worthy for Zhengzhou to spend such huge effort on autonomous bus development.

Figure 11 shows people's perceptions on who should be leading the autonomous bus effort. Based on the pie chart result, most people think Zhengzhou Municipal government, Zhengzhou Transportation Bureau, and Zhengzhou Bus Company should be leading this effort. Figure 12 shows the scenarios where the respondents are willing to take the autonomous bus. Compared with others, BRT and arterial roads win the top two highest votes.

Figure 13 shows that knowledge is similar across all three AB projects.

Figure 14 shows people's opinions on the autonomous bus fare. The majority (60.66%) of the respondents voiced that the fare should be the same as the traditional bus. 18.8% of the respondents thought that the fare should be lower than that of the traditional bus, with 2.33% stating that the autonomous service should be free. 20.54% thought the fare should be higher compared to the traditional bus.

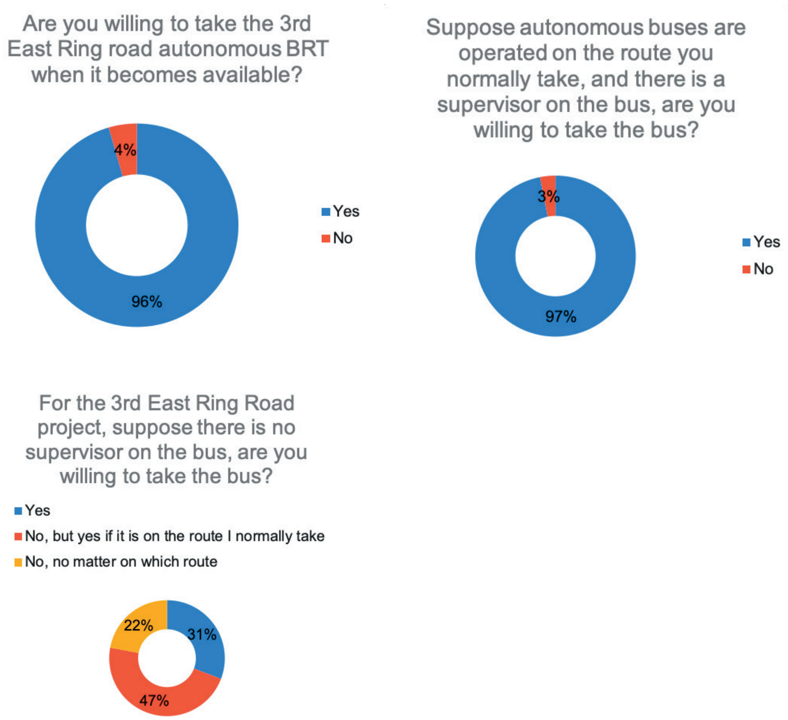



**Figure 8.** Responses to: (1) Are you willing to take the 3rd East Ring road autonomous BRT when it becomes available? (2) Suppose autonomous buses are operated on the route you normally take, and there is a supervisor on the bus, are you willing to take the bus? (3) For the 3rd East Ring Road project, suppose there is no supervisor on the bus, are you willing to take the bus?

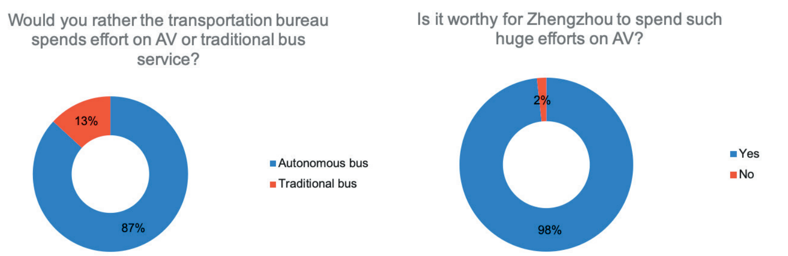



**Figure 10.** Left graph shows responses to the question *Would you rather the transportation bureau spends effort on AV or traditional bus service?*. Right graph shows responses to the question *Is it worthy for Zhengzhou to spend such huge efforts on AV?*.

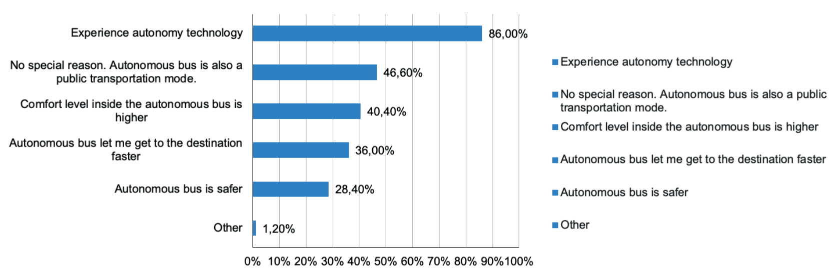
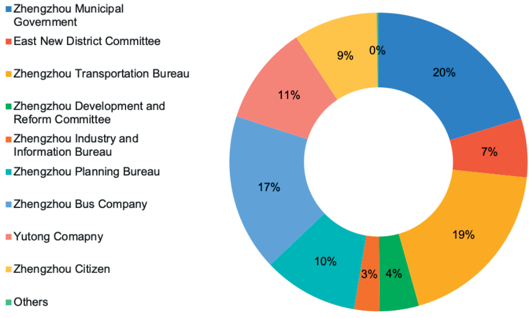



**Figure 9.** Responses to *What are the reasons for you to take the autonomous bus?*



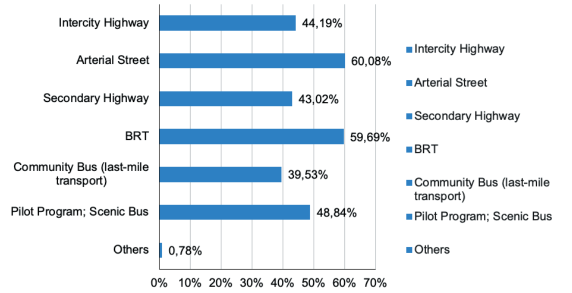




**Figure 11.** Responses to *Who do you think should lead the autonomous bus effort?*

**Figure 12.** Responses to *In what scenarios are you willing to take the autonomous buses?*

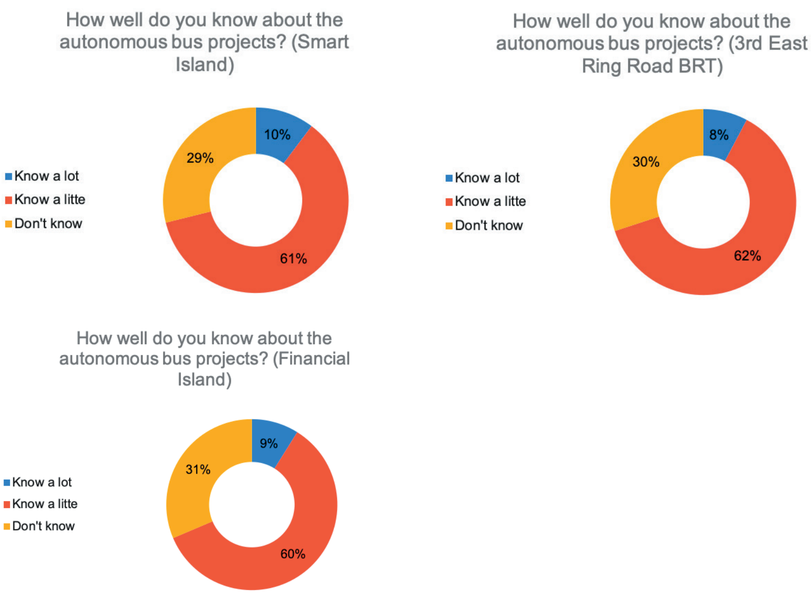



**Figure 13.** Responses to *How well do you know about the autonomous bus projects?*

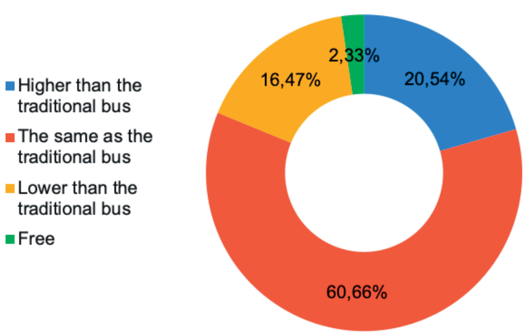



**Figure 14.** Responses to *How much do you think the autonomous bus fare should be?*

# Interview Results

## Unstructured Analysis

Qualitative analysis of the interview results revealed both consistencies and inconsistencies in stakeholders' perceptions of the AB projects and their role in them. Since interviewees were asked similar questions about the electrification campaign, we gained additional insight by directly comparing responses.

*Consistencies*

All interviewees agreed on the principal elements of the AB projects, and on the central concerns. All felt that the most important actor was the government. Additionally, they all agreed that the overarching goal and motivation for these projects is to develop AB technology and the broader economy of Zhengzhou. However, none was convinced that this technology would increase transit ridership. Many felt transportation planning, not technology, would determine this in the end. Lastly, they all agreed that safety must be prioritized. These results showed there is important agreement on the big picture elements of the project and the need to prioritize safety to ensure its success.

*Inconsistencies*

Inconsistencies between interviewees reveal key areas for recommendations. A divide emerged between Yutong's and the government officials' responses on the question of anticipated outcomes. While Yutong did not see downsides to the AB projects, government officials were concerned about the uncertainty of the new technology, especially considering safety and the large government investment required for the projects. Yutong identified profit as an important positive driver, whereas government officials mostly pointed back to the overarching goal of innovation leadership or did not mention anything when asked about positive motivations.

Another noticeable inconsistency was in organizational roles in the AB projects. Both the Municipal Bus Company and the Henan Provincial Government see themselves with small roles in the project. Interestingly, our user survey results indicated that many people think the Municipal Bus Company should be leading this work. Both the Municipal Transportation Bureau and Yutong see themselves as an important coordinating entity. Yutong also considers itself to be instrumental in transportation planning, which is traditionally a government role.

| | AB Projects | Electrification |
|---|---|---|
| **Consistencies** | Government-led<br>Goals<br>Impact on transit ridership | Government-led<br>Goals<br>Success factors |
| **Inconsistencies** | Pros and cons<br>Expansion feasibility<br>Agency roles | Change in goals over time<br>Expansion feasibility |
| **Takeaways** | Mix in overall opinion of projects<br>Need to address safety<br>Overlapping and unclear roles | Clear, quantifiable goals<br>Agency coordination |

**Table 7.** Summary of unstructured analysis of interview results

None of the interviewees self-identified as the lead on the project, though interviewees agreed that the Municipal Government is considered the lead. We were unable to interview a representative from the Municipal Government.

Finally, the respondents did not agree about whether AB projects should be expanded. Respondents from Yutong thought so, but the Municipal Bus Company did not. The Municipal Transportation Bureau and the Provincial Government both felt that the projects are too early in development to have a stance. These inconsistencies show a clear need for officials to communicate and align on these issues, including the potential benefits that all should be working toward, the risks to be looking out for, and the roles each should play to ensure seamless design and implementation.

*Electrification Comparison*

Interviewees were far more consistent on their answers about electrification of the bus fleet in Zhengzhou. This is likely to some extent due to the fact that these answers are retrospective, making it easier to identify what went wrong and right. It may also be due to differences in process and organization of electrification compared to the AB projects.

The interviews all identified a clear, quantifiable goal for electrification - to reduce air pollution and environmental impact of the buses. Each interviewee also identified discrete and clear roles: manufacturer (Yutong), lead (Municipal Bus Bureau), coordination (Municipal Transport Bureau), and promotion (Provincial Government). Interviewees agreed on the reasons for success, which reflect these clear goals and roles. The top-down structure of project execution, government subsidy, and agency coordination were touted as reasons for success.

The AB projects also have a top-down structure in place, and significant government investment. These elements suggest the AB projects are on the right trajectory for duplicating the success that electrification saw. However, agency coordination is much less clear at this point in the AB projects. Additionally, it tends to be much easier to unite around a quantifiable goal like reducing air pollution than a more abstract goal like leading AB technology development and innovation. This goal could be detailed more thoroughly to identify quantifiable and incremental markers of success along the way, and at the finish line. These markers may help to inform project progress, and motivate actors to work toward these goals despite uncertainty in the final outcome or timeline.

Though the COVID-19 response impeded our ability to conduct interviews with officials from all our case studies, we received a response on an abbreviated questionnaire from AMoTech, who works on the Swiss Transit Lab Route 12 project.

## Structured Analysis

Analysis of the structured data recorded during stakeholder interviews predominantly supports the conclusions drawn from the open-ended answers and unstructured analysis. We have grouped the main points from this analysis into three conclusions:

*1. There is disagreement among stakeholders of each others' attitudes and capabilities.*

*2. There is less citizen engagement with AB than with Electrification.*

*3. Significant tension exists between expectations for and desires for AB projects.*

*Disagreement over stakeholder attitudes*

This data analysis found major disagreement over the attitudes of specific stakeholders towards specific projects. For example, while the Zhengzhou Municipal Bus Company views itself as having almost no familiarity with the East Third Ring Road BRT project, other stakeholders ranked the Municipal Bus Company's familiarity as very high, medium, and low. This disagreement in perception is widespread among stakeholders, projects, and the three variables we measured for: Familiarity, Interest, and Resource Availability. These results are presented in Figure 15.

This supports our unstructured analysis by quantifying the significant friction and inefficiency within the planning process for ABs due to misunderstandings between key stakeholders. There is a clear need to

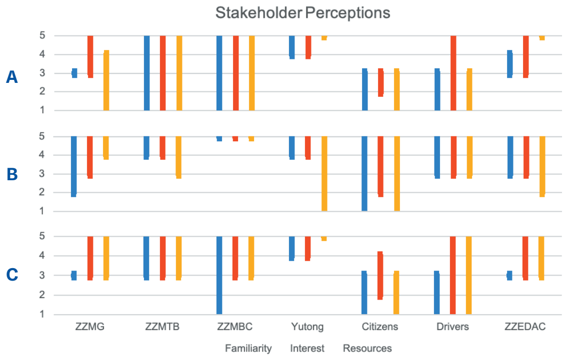



**Figure 15.** Distribution of ratings for how each organization orients towards each project.
Row A: AB Pilot
Row B: Electrification
Row C: Ring Road BRT

improve communication and coordination.

*Less citizen engagement with AB than with Electrification.*

Compared to their involvement in the past electrification program, the Citizens as a stakeholder group are not as closely involved with planning for the East Third Ring Road BRT project. We determined this from the "alignment" data in the interviews, which is represented in the force diagrams in Figure 16.

This result also supports the results from our unstructured analysis. The electrification program was a huge success in Zhengzhou, which we can attribute partly to the more inclusive design processes that tightly involved multiple stakeholders. Our structured data supports the conclusion that this is currently missing from the AB projects.

*Significant tension exists between expectations for and desires for AB projects.*

Our data shows disparities between each stakeholder's ranking of the potential of AB technology to fulfill certain societal goals and the priority of these societal goals in the planning process for Zhengzhou's East Third Ring Road BRT project. We illustrate this in Figure 17.

We draw two conclusions from this data. First, the rankings of priorities are uniformly lower than those for potentials, measured by median response. This shows that Zhengzhou planning officials may be showing an inflationary bias towards their own project. Second, "Technology Innovation" shows the least amount of bias—it is both the highest ranked priority and the highest ranked potential societal goal—while "Economic Development" shows the most amount of bias—it has the highest disparity. These observations suggest that Zhengzhou would benefit from more independent perspectives informing their planning process.

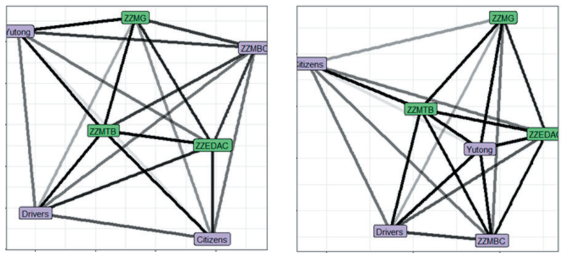
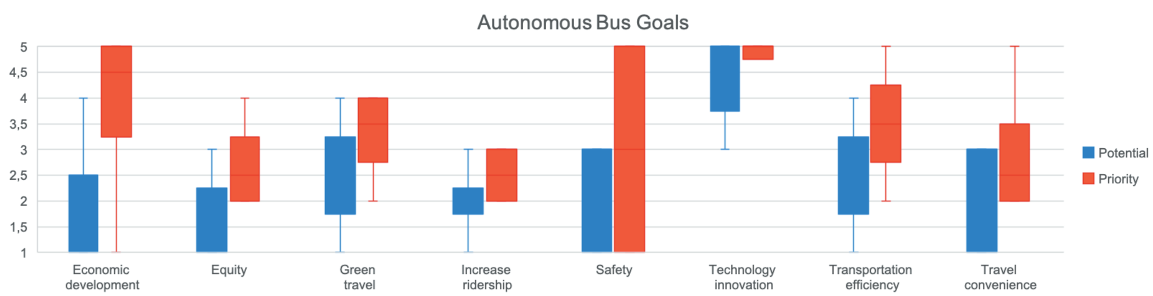



**Figure 16.** Force diagrams of alignment; Electrification on left, E3RR ABRT on right. Closely aligned stakeholders are clustered together more tightly, and less aligned organizations are repulsed.

**Figure 17.** Distribution of responses about priorities for and potentials of AB technology from 1 (low) to 5 (high)



# Recommendations

We have integrated our results to produce recommendations for Zhengzhou to capitalize on its strengths and to address its weaknesses for AB project development. We believe that an organized and coordinated approach will greatly help the city to achieve its goals of becoming a world leader in green, automated, and safe transit. Our recommendations are grouped into three sequential themes, as shown in Figure 18.

The themes are necessarily cumulative: successful planning early in the process ("Planning now for long-term success") is critical both to achieving near-term milestones and to supporting success on medium-term initiatives ("Ensuring Acceptance" and "Fixing the Economics"). In the following sections we outline the main recommendations contained in each theme, and make specific suggestions for application to Zhengzhou's context.

## Planning now for long-term success

### *Recommendation 1: Coordinate and Align Agencies*

The interview results reveal disagreement about each agencies' role on these projects, as well as their perception of the projects' priorities and potential. Agency coordination was identified as a key element of success for electrification. International case studies all implemented some form of long-term vision and agency coordination before launching their projects. Zhengzhou could benefit from bringing all stakeholders together and collaboratively defining their roles, priorities, and understanding of what this technology may be able to accomplish. They should consider these questions over the long-term, not just for the projects being implemented in the next few years.

We recommend that the Zhengzhou Municipal Government convene a one- or multi-day workshop with all stakeholders involved in the AB projects. The goal of this workshop will be to share hopes, concerns, and priorities for the projects, and to align understanding of each agencies' role. This workshop can also be the forum to define quantifiable metrics and establish incentives for cost reduction over time. The workshop should address any disagreements about what the project is for and what it can accomplish. Additionally, the workshop should lay out a vision for AB in Zhengzhou over the long-term. Workshop participants could also explore how to conduct better user engagement and ensure acceptance, and innovative designs that might help with the economics,which are recommendations under the second and third themes in this document. This workshop is foundational to accomplishing nearly all of the recommendations we found in our analysis.

**The Present** → **The Future**

**1.**
**Planning Now for Long-Term Success**
1. Coordinate Agencies
2. Quantify Targets
3. Establish Incentives

**2.**
**Ensuring Acceptance**
1. Maintain Security
2. Continue the Pilot
3. Drive Engagement

**3.**
**Fixing the economics**
1. Maximize Ridership
2. Diversify Revenue
3. Control Costs

**Figure 18.** Three recommendation themes.

*Recommendation 2: Establish Quantifiable Metrics*

The interviews revealed agreement on the main goal of the AB projects: to develop autonomous technology and expand the regional economy. However, the interviews revealed a lack of agreement on how and whether the projects could achieve that and auxiliary goals. To ensure all stakeholders are clear on what defines success, it is important to establish quantifiable metrics. Electrification was successful in part because of the easily quantifiable goal of reducing air pollution. Metrics should be established for final project success, but also for incremental success so stakeholders have an idea of how the project is progressing. Metrics can also help to motivate stakeholders to work toward the same goal, guiding agency coordination and highlighting the potential for success. Some examples of suitable metrics include: (1) to provide rides to over 50,000 people each calendar year, and (2) to earn an excellent safety rating from two consecutive user surveys.

*Recommendation 3: Establish incentives for stakeholders to reduce costs over time*

Interviewees agreed that government financial support through subsidies was key to the success of electrification, and also that there are similar subsidies enabling the AB projects. While interviewees felt that Yutong would be able to make a profit in the subsidized program, it is not clear if this model is sustainable in the long term. Stakeholders should determine ways to reduce the government subsidy needed over time while retaining profitable opportunities for the private program partners like Yutong. A simple approach could be government commitment to a long-term subsidy road map that predictably declines over time. This takes a similar approach to the Chinese national government's approach to personal electric vehicle subsidies, which has been a very successful program.

## Ensuring acceptance

*Recommendation 1: Maintain feelings of security by maintaining the bus attendant.*

According to the survey results, Zhengzhou citizens are generally very supportive of autonomous bus deployment, but the proportion of people that were still willing to take the bus when no bus attendant was present decreases dramatically. The bus attendant should be maintained on all autonomous buses for the foreseeable future in response to these concerns.

*Recommendation 2: Continue to operate the Intelligent Island Pilot.*

Figure 19 shows that people that have taken the smart island buses before are more likely to take the East Ring Road BRT autonomous buses when they become available, and their acceptance levels of not having a bus attendant on board are higher as well. The pilot should continue to operate for the foreseeable future to improve citizen's perceptions of ABs.

Yutong should maintain and even expand the Smart Island pilot project service, considering people who have experience with ABs tend to have more positive perceptions and a higher willingness to take ABs in the future. Yutong can work on reducing the time interval between buses and increasing the number of scenarios the buses cover, since these are the two aspects that the survey respondents were least satisfied about.

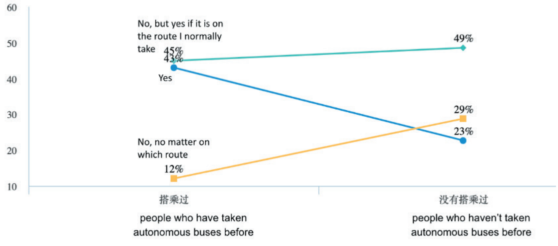



**Figure 19.** Responses to *For the 3rd East Ring Road project, suppose there is no supervisor on the bus, are you willing to take the bus?*

*Recommendation 3: Meet the needs of riders by increasing citizen engagement.*

According to the interviews, we find that the Zhengzhou residents are largely excluded from the decision making process of the autonomous bus development. Inspired by the "design jam" practice of Transport Scotland, we propose that the authority develops more user engagement approaches. The design jam is part of the CAVForth project, which aims to develop the autonomous buses practices in Scotland. Design jam brought together East Scotland's citizens with researchers, designers, developers and Stagecoach leadership to co-design how this service works for real people. This is a one-day event throughout which the participants got to learn about the technology and the autonomous bus service, and were encouraged to create ideas as well as prototype solutions. Each participant even received a £20 gift voucher as compensation. Zhengzhou could implement a similar workshop to inform the design of AB projects and increase user support.

Since the ridership of autonomous buses will highly depend on public acceptance, it is essential to monitor public perception on this technological development. Alongside the introduction of Route 12 in Switzerland, the Institute of Science, Technology and Policy (ISTP) at ETH Zürich carried out a panel survey with three waves on the public perceptions of the test run as well as autonomous driving in general. The panel survey study with the local residents managed to assess whether and how the autonomous bus trials affect public perception, specifically regarding doubts and fears from a scientific perspective. It is essential for Zhengzhou to also conduct surveys periodically to understand public perceptions towards autonomous bus development. The survey we conducted in this research can serve as a starting point for future surveys.

*Recommendation 4: Implementing suggestions from the user survey*

The authorities should increase the availability of information for the population. For each autonomous bus project, the survey found that only about 10% of the respondents consider themself well-informed about it. A number of respondents also suggest the policymakers to "strengthen the propagation" of the autonomous bus projects. Accordingly, we suggest the authorities improve on providing information regarding the communication of the background of the project implementation. For example, they can advertise the existing and upcoming autonomous bus projects using displays around the Intelligent Island Pilot and at the proposed autonomous BRT stops.

For future autonomous bus deployment, the authorities can consider prioritizing BRT & arterial roads, compared with community buses and inter-city highways, since the former two are more popular with the survey participants. Also, they should develop autonomous buses on routes that people normally take, since this will attract more people to "buy-in" the new service, which also necessitate the policymakers to gauge people's perceptions towards this new technology through various approaches such as surveys.

Based on survey respondents' answers to the bus fare questions, the autonomous bus price should not be higher than that of the traditional bus.

## Making the economics work

*Recommendation 1: Maximize ridership*

The first priority when building an economically sustainable transit network is to ensure a strong ridership base. Only when the ABs are operating at high utilization rates will the economics begin to make sense, since per-user fares will continue to drive revenues. Maximizing ridership will necessarily build off of successful efforts to build project support among the general population in Zhengzhou, which is the focus of the previous theme, "Ensuring Acceptance." To convert public acceptance into ridership is largely a matter of executing on traditional transit planning, in which Zhengzhou is already expert. The most important factor for use of a transit line, after accounting for sufficient service quality and ride satisfaction, is the utility of the route itself for the passengers (Lai and Chen, 2011).

*Recommendation 2: Research alternative uses for AB platforms during times of low utilization*

Despite best efforts to build ridership, public bus transit in China still requires substantial government subsidies in order to provide a socially optimal level of service (Yang et al., 2020). Creative asset repurposing can shrink or eliminate the amount of required subsidization. Traditional bus networks have unavoidably low utilization rates during overnight and holiday periods, due to basic human mobility patterns. By recasting ABs as flexible mobility platforms instead of as human transportation vehicles, these "dead hours" can become important revenue streams. Considering the much lower ratio of operating costs to fixed costs in the AB asset model, especially if the need for human supervisors and assistants is eliminated, overnight revenue streams become even more valuable to the economic success of AB transit.

Inspiration for off-hour operational models can come from the innovation ongoing in the autonomous personal vehicle market. The COVID-19 pandemic has created a protracted low utilization for most types of transportation, and thus has engendered experimentation of non-passenger business models. Neolix and Navya/Beep autonomous mini-buses have been used in the USA to deliver medical supplies. The Chinese startup Pony.ai has recently begun using its AVs to deliver packages and groceries to house-bound consumers (Wiggers, 2020). With the prioritization of cargo bays during the AB design and manufacturing processes, off-hour delivery services could supplement transit revenues. By creating a third-party bidding platform for off-hour services, the municipality can further take a hands-off leasing approach. To implement such a model, Zhengzhou and Yutong would need to engage in a national conversation: the regulation of public transit and commercial transportation is separated in China at present. We recommend exploring this option further to take full advantage of AB's potential value.

Beyond off-hour monetization, alternative uses that deliver public value despite not generating additional revenue should also be considered. Although bus attendants and supervisors will be needed on AB transit systems for the foreseeable future, there is potential for those roles to provide extra value to offset the labor cost. Cross-trained government personnel in public health can simultaneously offer AB supervision while also providing health information and preventative treatment. Similarly, concierge services can be deployed to keep citizens aware of recent developments or government directives, and also to improve tourist experiences.

The above use cases do not require more than minimal modification to the standard large bus format. A wider set of possibilities becomes available when the AB manufacturer considers radical redesigns of the bus into a more general autonomous mobility platform.

*Recommendation 3: Controlling costs*

The two preceding recommendations have focused on revenues, but the overall economics depend on costs as well. To a large extent, traditional program oversight and efficiency measures will be sufficient to rein in costs in AB transit, so Zhengzhou need not prioritize this area as much. On the other hand, the cost structure of AB transit will likely shift significantly away from variable operations costs (drivers) towards capital costs (initial bus purchasing and maintenance). Such cost model shifts will require careful analysis of new contracting structures, specifically surrounding maintenance and repair costs.

As discussed in Recommendation 2, not all benefits of AB transit may be monetizable, and so a pure "Value = Revenue — Cost" calculation to determine program net benefits is inappropriate. When communicating the overall usefulness of AB transit, the government and its business partners should strive to include also the less tangible public benefits of its services.

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Chapter 2.

# *Creating a Livable City through Transit-oriented Development*

Matías Williams, Neha Doshi, Camila Ramos

# Introduction

Rapid and unplanned urbanization is happening across cities around the world. Under this scenario, transportation plays a fundamental social role in fostering economic development by providing access to opportunities. Today one of the greatest challenges for cities is to achieve urban and transport sustainable growth, for which Transit Oriented Development (TOD) has proven to be one of the most successful approaches.

The TOD concept appeared first in the 1980s and has since then received increasing attention from researchers and city officials. The concept of TOD constitutes one of the most important strategic initiatives for city development, as it merges together transportation, land-use planning, and urban design to deliver a comprehensive solution to contemporary urban challenges.

Despite TOD's multiple benefits — promotes healthy behaviors, fosters better access to more services and opportunities, and increases urban vibrancy, among others — achieving transportation and land-use integration requires a collective effort from multiple actors and city officials in order to define a cogent, forward-looking strategic vision of the future (Suzuki et al., 2013). Cities need to aim at increasing urban densities, diminishing sprawl, and providing high quality access through transit; however, this cannot be achieved without the adequate institutional framework and financial model.

There are many other elements that need to be set in place for cities to profit from successfully integrating transit and land development. Transit systems — such as bus rapid transit and subway investments — need rapid growth, rising real incomes, and increased density to yield economic benefit. These conditions are already occurring in the developing world, and China is no exception: it "has been experiencing rapid urbanization during the past decades, and over 70% of the total population will be urban by 2035" (Li et al., 2019, p. 3). Thus, it is no surprise that the TOD concept has also experienced a great development in the past decades; in fact, "research literature on TOD in China has dramatically increased" in the last two decades (Xu et al., 2017, p. 4). Figure 01 summarizes the number of journal articles related to research on TOD in China in the Elsevier database (Xu et al., 2017). Under these conditions, it is clear that TOD is an appropriate approach for any city facing such levels of urbanization. However, to fully unleash the development power of TOD requires deep changes in how urban development and planning is held within a city. For instance, governments need to adapt their laws and change their land policies to allow for mix-use development and a better integration of public transit stations with its surroundings. Additionally, measures to discourage the use of private cars, such as reducing parking lots, are key to providing a better framework for TOD initiatives.

In the last few years, the understanding of TOD implementations has increased, however, there are limitations to the possibility of extrapolating policies or copying them from one case to another. Guthrie and Fan illustrate this by comparing the cases in the United States and China, and expressing that there are different circumstances and characteristics that make it impossible to implement United States TOD strategies in Chinese cities (Xu et al., 2017) Hence, some TOD concepts need to be altered to support TOD projects in China. Indeed, we propose a framework that adapts all these concepts to adapt to any city around the world.

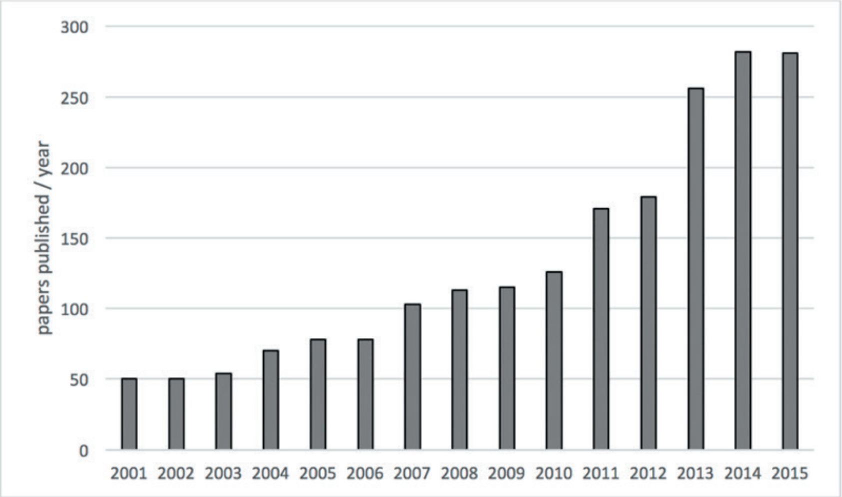



**Figure 1.** Journal articles on transit-oriented development, Papers published on Chinese study areas with keyword "transit-oriented development" in the Elsevier database, 2001–2015. Source: (Li et al., 2019, p. 3)

# Literature Review

Many authors have written about the benefits of TOD as a planning policy or strategy. From increasing the land value next to stations to having a more walkable city, to reducing pollution, to improving citizens' quality of life (Huang & Yin, 2015; Kay et al., 2014; Shen et al., 2018; The TOD Standard v3.0, 2017; Yu et al., 2018). However, there are no clear indications of what makes a good TOD project. Several researchers and practitioners have tried to dissect TOD projects to better understand key elements from them. Indeed, there are studies proposing different typologies or ways to classify projects, some analyzing how to transfer good practices from one place to another, many describing key factors from successful or notable cases, and others seeking to understand the effects on the local community,

Due to this lack of clarity, scholars tend to divide the types of TODs given its typology because it is particular for each zone (Ibraeva et al., 2020; Shen et al., 2018). There are various ways to categorize projects given its typologies. Ibraeva et al. (2020) describe all the different typologies, starting from the framework that only considers land-use and transportation, known as node-place approach, to the different variations of it. Indeed, over the past few years, there were several contributions to this framework, adding crucial aspects such as walkability, site potential for TOD, modal splits, density and amenities, among others.

Additionally, many studies have been focused on why TOD projects that work in some place, do not necessarily work on another. This concept, called project or policy transferability, is essential to understand what are the factors that make a project succeed even though projects are adapted for each country (Chen, 2010; Thomas et al., 2018; Zhang, 2007). Most of the studies shared the same conclusion, general standard guidelines cannot be applied everywhere without having into consideration site-specific conditions and characteristics. To sort the issue of project transfer or policy transfers from one site to another, researchers have designed analysis to determine critical success factors, that are not policies but elements that are needed to see a project succeed (Thomas & Bertolini, 2015).

Analyzing different typologies or success factors is not enough to completely understand projects. Over the past several years, exhaustive studies have been done over projects around the globe (Ibraeva et al., 2020). Starting with the notable cases like Amsterdam that at least European planners consider a success story, due to its high acceptance rate, the low use of private cars and the general adoption of public transportation across the entire region (Forsell, 2016; van Lierop et al., 2017). Other cases are not that successful. For instance, in the US, many cities have seen an increase in real estate values due to TOD-like policies. Still, the general adoption of public transportation in lieu of private cars is not happening at the expected rate (Duncan, 2011; Zhang, 2007).

A separate library is devoted to analyzing cases in China (Xu et al., 2017). From hedonic models to understand the impact of TOD policies in the real estate market (Huang & Yin, 2015), to cases such as Nanchang or Urumqi, that are not really well-known, but their experiences could contribute to better understanding how TOD policies could be applied in China (Mu & de Jong, 2016; Suzuki et al., 2015). Close to Hong Kong, many of these studies based their analysis in the successful case of Hong Kong TOD (Cervero & Murakami, 2009). The case of Hong Kong is emblematic because they adapted a financing model to suit rail development and land next to the stations without recurring to the already known Public-Private Partnerships, called Rail + Property (R+P) (Cervero & Murakami, 2009). Also, Seoul and Tokyo are good examples that Chinese researchers and planners are always looking at. In this sense, the bibliography is very comprehensive of different factors such as political stability, financial mechanisms to promote transportation infrastructure, novel ideas regarding the mixed-use of the land next to transit corridors.

But all of these cases are not enough to explain why we want to implement more TOD projects. To answer this question, it is essential to recognize the social role of transportation and the opportunities cities provide to its citizens (The TOD Standard v3.0, 2017). Planners need to think about how to provide a better standard of living within cities and promote social equity. Thus, the role of TOD projects should aim not only at raising more money to build more transportation infrastructure but also to increase the social equity in the zone, by providing affordable housing, free open public spaces, amenities that do not discriminate (The TOD Standard v3.0, 2017). The city should be for all, and a TOD project is part of the city.

# Methodology

The concept of TOD has evolved since its first conception in the eighties, and though several cities have intentionally implemented TOD policies, many of the current examples that can be named as being TOD projects were not conceived as such at their initial stage. As multiple transit projects have evolved, the TOD concept and what it entails has evolved with them. Thus, cities looking to embrace TOD benefits struggle with implementing the changes and policies necessary to push forward successful projects, that is, projects that achieve in the long-term financial revenues, increased densities, better access, and economic growth.


**Figure 2.** Methodology, Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

In order to address this challenge many cities face — and Zhengzhou city is no exception — we developed a methodology that allows us to collect valuable experience from cities around the world, translate it into quantifiable data, and identify development gaps in terms of project maturity and completeness.

Our methodology begins by collecting data from Chinese and international TOD projects that have proven successful in one or multiple aspects. We categorized these aspects in three essential groups: design, finance, and policy. Each of these elements contributes to TOD success by focusing on different goals to achieve. By including the design element, we ensure to include as a metric the urban quality of the project in question, that is, those elements or urban design — such as land usage, transit integration, multi-modality, public space, and transit design — that will contribute to improve the quality of life of those whose lives will be impacted by the project. Including the finance element allows us to understand the mechanisms through which governments have secured capital to promote infrastructure construction and operation. Frequently these mechanisms involve creating innovative policy frameworks that allow public and private players to share risks and rewards. Finally, by considering the policy element we make sure to evaluate the project in terms of feasibility by analyzing whether the regulatory framework and necessary governance have reached the maturity required to implement TOD; in other words, we evaluate how ready a city is to foster a project of this nature.

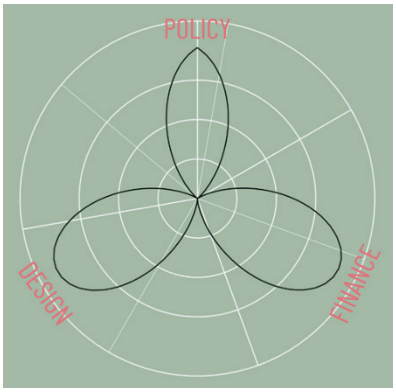



**Figure 3.** TOD clover,
Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

Figure 03 illustrates the three elements aforementioned, which we have condensed into the concept of TOD Clover. Each of the elements contained in this scheme is relevant to achieving success when implementing TOD, however, in order for cities to truly benefit from transit development, the three elements — design, finance, and policy — need to function as well-calibrated gears, moving towards the same goal.

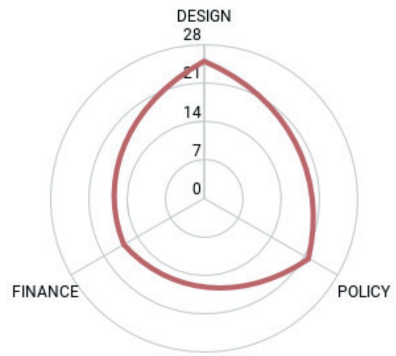
For each of the clover's elements, we can identify several ideas, concepts or mechanisms that have been used in the literature and by cities to achieve success in TOD. By reviewing several case studies we are able to identify those factors which were determinant for a TOD project either because they allowed the project to flourish and render positive economic and urban development, because they provided innovative ways to leverage capital, or because they enabled coordination between different stakeholders. We have named these factors Critical Success Factors (CSF) and they constitute the base for our quantitative methodology.

Following Thomas and Bertolini's (2015) framework to evaluate TOD projects in different parts of the world, we propose an adapted model that includes Chinese cities and the features mentioned in the guidelines published by the Institute for Transportation and Development Policy (ITDP)(The TOD Standard v3.0, 2017). Many of the critical success factors identified in the literature remain similar, but some definitions and values for each one have been adapted in order to incorporate the particularities of the Chinese case. First, the CSFs are translated into a scorecard which contains questions and a grading scale in order to gather objective answers from city officials or other stakeholders (please refer to Annex 01 for further information). Second, aiming for city-wide TOD strategies, our framework is based on a developing TOD policy, from local to metropolitan projects. For example, if a city considers only local TOD initiatives and does not contemplate transit corridors to larger urban areas, our methodology penalizes this approach and makes it difficult for a project to score more than half the points for each question where applicable. This emphasizes the idea that TOD should be approached in a holistic way, as a mechanism that contributes to many aspects of daily life and not only as a real estate development project.

The scorecard we have developed is the tool that allows us to assess in an objective way how close or distant is a project from the practices and policies that have proven to be effective in past experiences. In this publication, we determine the score for several projects — both international and Chinese — in order to gather a rich database of good practices, and also to assess where do Chinese cities stand compared to other cities in the world.

The scorecard is an efficient method to quantitatively compare and identify those elements in which Chinese cities excel, and those in which they struggle. Our methodology also makes it possible to work with city officials, as they can also assess their own projects by evaluating them with this methodology.

**Figure 4.** TOD scorecard results for a given project, Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams




# Analysis of findings

Transit Oriented Development plans in Zhengzhou are in their initial phases of development.  A preliminary visit to Zhengzhou city laid the groundwork for our analysis and policy recommendations. Zhengzhou's urban form can be considered through the framework of old and new. Newer parts of the city are organized according to function and are orderly. There is the Smart Island where autonomous vehicle buses are tested and the Business District designed to draw both national and international firms. Older parts of the city are denser and bustling with activity, their layout less planned. Metro transportation--though not expansive in its reach--moves residents through the city. Since its inception in 2000, the Zhengzhou metro system has built five subway lines. Still, roads remain congested with cars, two-wheelers, and buses during peak hours, contributing to the poor air quality and prolonging travel times. Improvements to the existing metro design carry the potential to increase ridership. The issue of "last mile" transportation was highlighted by city mayor, Xu Liyi (Liyi ,X., personal correspondence, April 16, 2020). A lack of pedestrian and bike friendly infrastructure makes completing trips more cumbersome for metro users who currently have to traverse across expansive rods to access various metro points. We regularly heard from government officials that metro expansion is critical to transport a larger percentage of Zhengzhou's growing population and make the subway a preferred mode of transport.

Metro construction costs are expensive. Passenger fare--measured by distance travelled--is highly subsidized, with the longest trip in 2020 costing approximately ¥9. Additional subsidies further discount trip fare for students and the elderly. Transit oriented development with a focus on Rail+Property financing offers a route to secure financing required for metro expansion while also integrating amenities and services with transportation (Hou, personal interview, March 25, 2020). This bundling of services and amenities enhances the passenger experience and helps create urban vibrancy.

Transit oriented development has ranked high on Zhengzhou city's political agenda. The city mayor has issued a directive to promote TOD thinking in relation to the city's larger transportation and urban development plan. Yasin Holdings--a local real estate company--has entered into a joint venture with Zhengzhou Metro Real Estate, a division of Zhengzhou Metro. Under this partnership, Yasin will take on the site development and construction components of TOD projects, while Zhengzhou Metro Real Estate will establish the TOD guidelines and conduct feasibility studies. This partnership has already proposed and designed TOD projects for future metro stations However, Yasin has struggled to navigate the city's policies, secure land, and bring their TOD designs to life.

Traditionally, China's strict land use and planning policies have not been designed to promote TOD projects. Mechanisms for land transfer remain a complex challenge and changes to floor area ratio (FAR) and land use are difficult to push through (Suzuki et al., 2015). TOD projects present uncharted territory for governments and real estate developers alike, increasing the amount of risk stakeholders have to take on. Chinese cities such as Nanchang and Shenzhen have developed strong frameworks to support institutional coordination and risk sharing (Suzuki et al., 2015).

Using our TOD scorecard, we asked collaborators from Shanghai Jiao Tong University and Yasin Holdings to assess the current TOD landscape in Zhengzhou. In Figure 06. we plot the average score given to TOD projects in Design, Finance, and Policy.

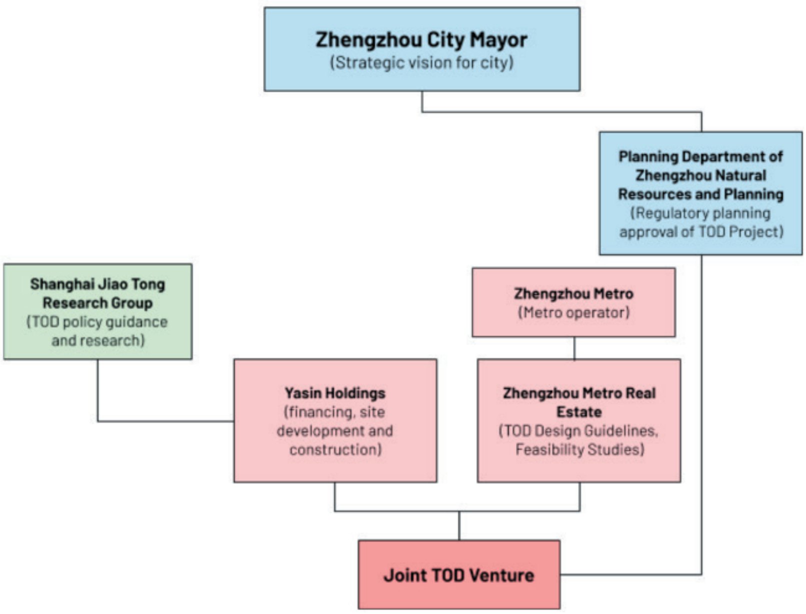
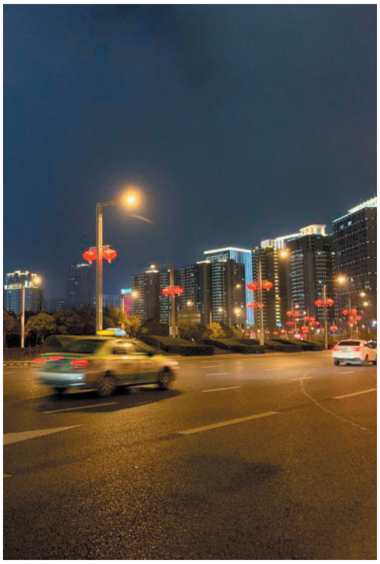



**Figure 5.** Zhengzhou TOD stakeholders,
Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

Long lines to enter a subway station in downtown Zhengzhou.
Credits: Neha Doshi



Expansive roads difficult the "last mile" transportation.
Credits: Neha Doshi

A mixture of shopping amenities and public space make areas around a subway station in old Zhengzhou vibrant.
Credits: Neha Doshi

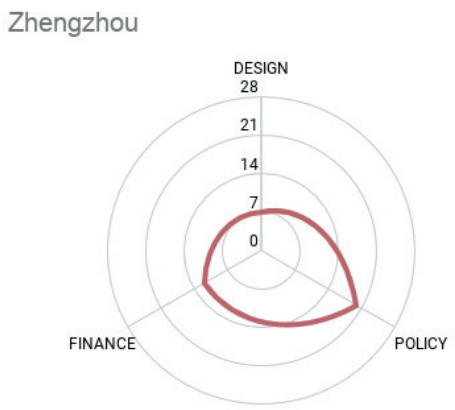



**Figure 6.** TOD scorecard results for Zhengzhou, Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

Our interviews with Yasin Holdings and officials from the Zhengzhou Planning Department and Zhengzhou Transportation Department further validate these findings (Hou, personal interview, March 25, 2020; Liu, Y., personal interview, March 20, 2020). Policy innovations that address current restrictions on land use make it difficult to actualize the proposed TOD design plans. A lack of transparency and appropriate risk allocation between the city government and private developers makes it difficult for Yasin to. In the following sections, we offer a series of recommended best practices that the Zhengzhou government and TOD partners can institute to further strengthen each leaf of the TOD clover.

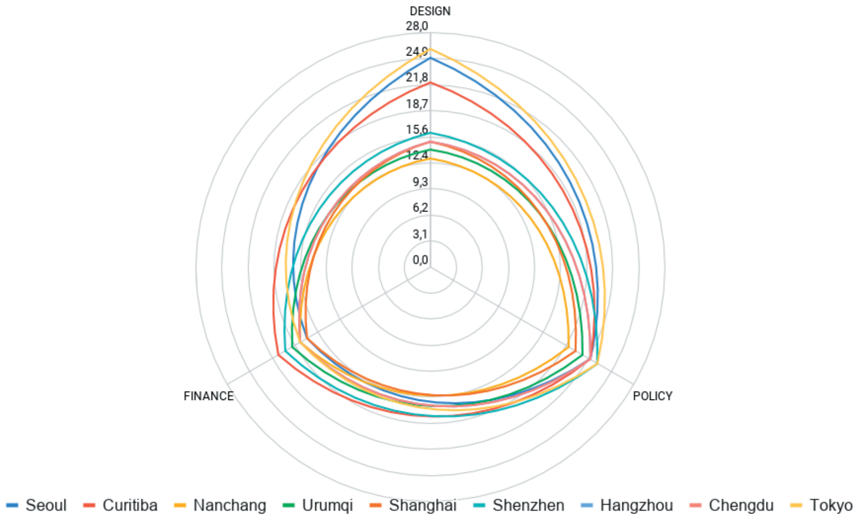



**Figure 7.** TOD score card results comparing nine cities,
Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

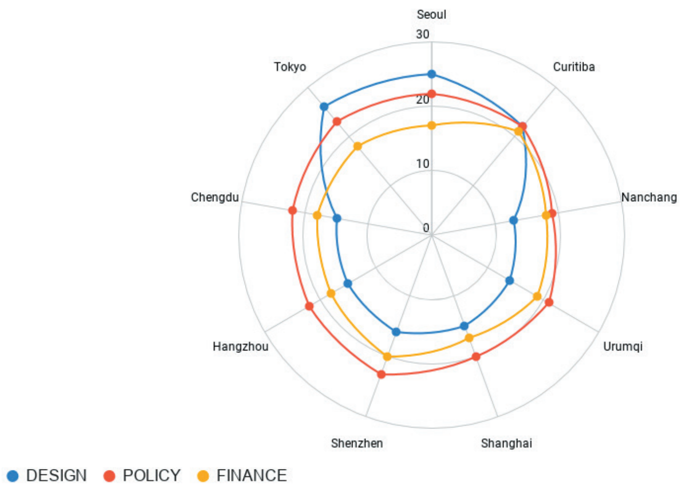



**Figure 8.** TOD score card results evaluating individual city performance,
Source: elaborated by authors Camila Ramos, Neha Doshi, and Matias Williams

# Good practices

## Design

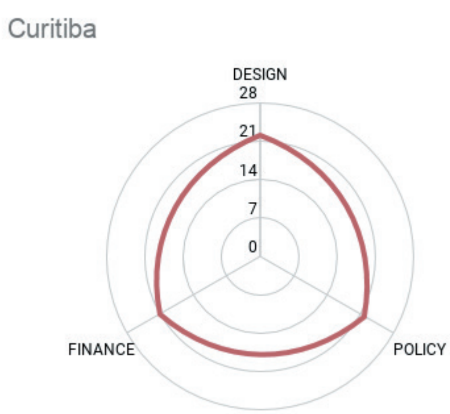
*Curitiba, Brazil: The beginnings of TOD*

Curitiba was one of the first cities to incorporate TOD concepts in its master plan. In the 1960s the city's vision established that urban growth should be organized along linear axes concentrating high population density and mass public transport (Duarte & Ultramari, 2012). Two of these corridors present the highest concentration of population and diversity of services, commerce, and public facilities—which correspond to basic principles of TOD, though by the time Curitiba developed TOD was a newly founded concept.

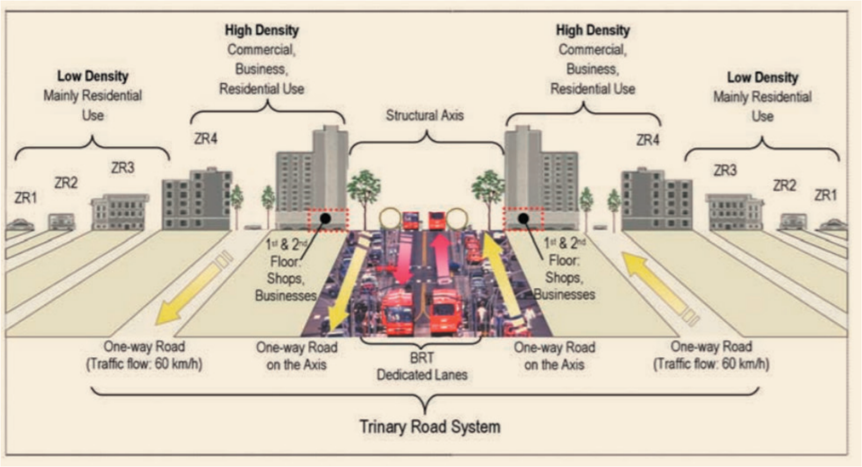
Curitiba's planning for people rather than cars has placed transit development in the center of urban growth. By the 2000 decade, the city already relied heavily on a well-developed BRT network which managed to carry 2.1 million passengers a day, twice as many as in 1990 (Suzuki et al., 2013). The city implemented multiple regulations to ensure transit-oriented built form: the government mandated that all medium and large-scale developments should be sited along a BRT corridor; a specialized independent entity – the Institute for Research and Urban Planning – was created to ensure land use and transportation integration; and the Trinary Road System was set in place. The Trinary system is a design element consisting of three parallel roadways with compatible land uses and building heights that taper with distance from the BRT corridor (Suzuki et al., 2013). This purpose of this system was to increase accessibility by promoting different land use paired with different built environments and transit infrastructure.

**Highlights**

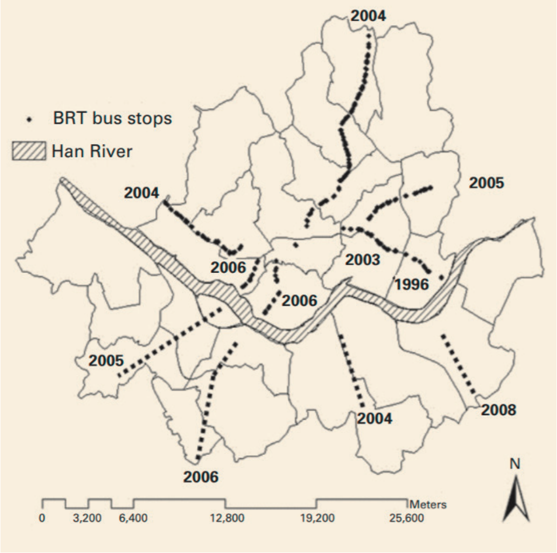
- Changes in Curitiba were only possible thanks to its political continuity and commitment to the city's vision of placing people first.
- The city's master plan contemplated TOD design, based on urban growth along linear transit axes.
- BRT corridors improved accessibility, which combined with mixed land use, attracted amenities.




Sustained political commitment has been an important part of Curitiba's success. The harmonization of transit and land use took place over 40 years of political continuity, marked by a progression of forward-looking, like-minded mayors who built on the work of their predecessors.
(Suzuki et al., 2013).




The Trinary Road System contemplates diverse land use regulations and transit infrastructure.
Source: Suzuki et al., 2013




BRT network in Seoul. Bus average speeds increased from 11 km/hr. to 21 km/hr.
Source: Cervero & Kang, 2011

### *Seoul, South Korea: Reclaiming public space*

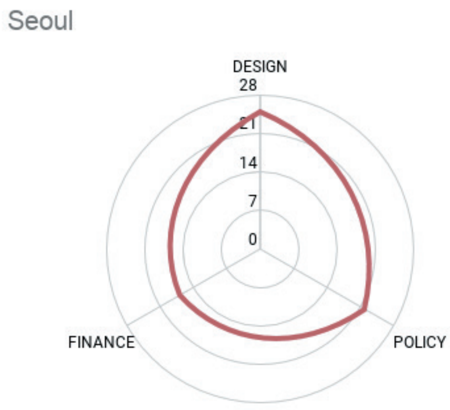
Seoul, a city which has experienced increasing densities and congestion since eighties, set in motion a plan for urban regeneration which would allocate space and resources – previously dedicated to building highways – to the development of public spaces and the densification of downtown. These changes were led under the administration of president Myung-Bak Lee, former mayor of Seoul, who was inspired by the Curitiba case.

Seoul's main project was the removal of a six-kilometer elevated freeway in Cheong Gye Cheon (CGC), and the restoration of an urban stream and pedestrian-friendly greenway (Suzuki et al., 2013). Additionally, a surface-street intersection was converted into an oval green park, which has become today one of the city's most popular places. Reclaiming space for people that had been previously allocated to cars demanded also an improvement of the transit network in order to absorb traffic and achieve an increase in the public transport modal share. The city achieved this by extending their subway lines and also opening seven new BRT lines.

The increase in accessibility, along with the development of public space, allowed markets to internalize these gains. The development of amenities along high-density corridors increased prices of homes within 2 km as much as 8 percent (Kang & Cervero, 2009) whereas land price premiums of about 5–10 percent have been recorded for residences within 300 meters of BRT stops (Cervero & Kang, 2011). Commercial and high-value-added industries – such as high-tech companies and innovation centers – also increased their land value. For retail shops and other nonresidential uses, premiums were more varied, ranging from 3 percent to 26 percent over a smaller impact zone of 150 meters from the nearest BRT stop (Cervero & Kang, 2011).

**Highlights**

- Clear vision and policy intentions: transformation of space for cars to space for people.
- Expansion of the public transport network helped absorb the congestion derived from the demolition of highways.
- Investment in greenery and open space, along with mix-use development increased.




"In a congested city like Seoul, increased accessibility derived from subway and BRT expansion encouraged developers to intensify mixed land uses along transit corridors. By doing so, land markets were able to capitalize these accessibility gains."
(Suzuki et al., 2013).

↖ Previous elevated freeway in Cheong Gye Cheon.
Credits: “Paradigm shift in Seoul”, at https://medium.com/

↑ New Cheong Gye Cheon at night during lantern festival.
Credits: https://worldwideavailability.files.wordpress.com/

← The city of Curitiba has developed along BRT corridors.
Credits: https://tod.niua.org/

↙ Rail+Property mechanism in Shenzhen has allowed for rapid land value appreciation.
Credits: Kayak.com

↓ Shenzhen’s Central Business District of Futian.
Credits: Futian Shangri-La at https://hk.asiatatler.com/

## Finance

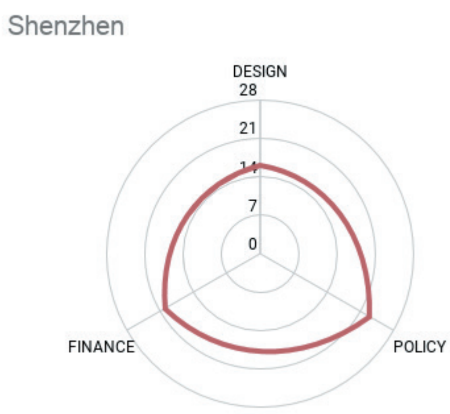
*Shenzhen, China: Land Value Capture (LVC) as a financing tool*

Shenzhen is a known case in China which has implemented a mechanism called Rail+Property (R+P) following Hong Kong's model. They have been able to design and put in place this kind of novel model mainly because they are a special economic zone, which gives Shenzhen a higher degree of freedom to change some regulations and laws.

However, models like R+P are still in the reach of other Chinese cities. R+P consists of capturing the land value appreciation next to stations though different mechanisms. For instance, the government could implement auctions with special conditions allowing only a few bidders to bid to keep the bidding price down and land-concession fee reimbursement, allowing for much larger profit after the subway or rail is built. Another mechanism is that the government transfers land to the subway company as a capital investment, so they can profit of future land development. This allows them to access land-use rights free of charge and benefit from a majority of the future land premium (Xue, L., & Fang, W., 2017). Evidence shows that the outcome of implementing R+P is a direct increase in the land and property value close to stations and corridors which allows for greater revenue for developers and the subway company.

**Highlights**

- Rail + Property financing tool that capitalizes on land value appreciation.
- Flexible financing options allow risks to be allocated to those who can best bear it.
- Homes within 400m of stations saw an appreciation of 23%; those within 600m saw an appreciation of 17%.




"The efficiency of R+P development is affected not only by whether the metro company is state-owned or private, but more importantly by whether the government has put in place effective monitoring, performance evaluation, and incentive mechanisms for metro companies to break away from over-dependence on government funding, and to be business-savvy and cost-efficient while cultivating a sense of social responsibility."
(Xue & Fang, 2017)

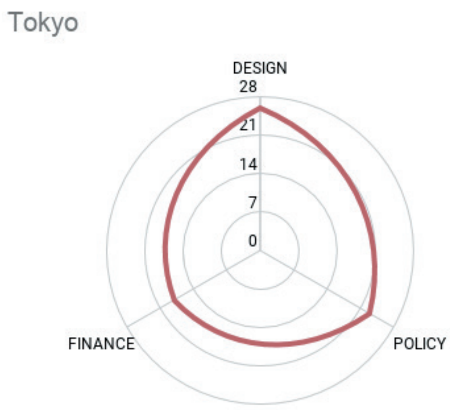
## Policy

*Tokyo, Japan: Private-led TOD*

Tokyo's Futako-Tamagawa is a major rail station located in the Setagaya Ward. This place is of particular interest because - aligned with the TOD principles - was redeveloped from 2000 through 2015, creating a livable community. This case is extremely relevant to planning because it was not the government in charge of urban renewal but a private railway company. Even though the government did not lead the renovation, they provided different resources that the landowners, business owners, and the company benefited from. For instance, the government provided loans to build transit-oriented infrastructure; they put in place regulations that allowed landowners to increase the land value through cooperatives to join different parcels and develop as one; they approved an increased the floor-area ratio next to stations (World Bank, 2017). In short, this case is a vivid example that urban renewal and TOD principles do not depend only on the government, and private companies could lead the way.

**Highlights**

- Renovation project led by a private railway company.
- Regulation allowed for single landowners to form a cooperative body that brings their properties together as a sole property providing for greater FAR and construction. Hence, increasing the value of each property.
- The national government provided financial tools that subsidizes transit-oriented infrastructure and facilities




"Tokyu Corporation has successfully combined land value capture with rail development to increase ridership across new lines, generate steady cash flows and re- coup investment costs."
(World Bank, 2017)

*Nanchang, China: Strong institutional coordination and regulatory framework*

Nanchang, China is the largest city and capital of Jiangxi Province. The city's growing population is predicted to reach 3.5 million in core city areas by 2025 (Suzuki et al., 2015). Rapid urbanization compounded by strong GDP and population growth have led to an increase in car and bus usage. Traffic surveys suggest that public transportation accounts for only 13.5% of total daily trips. The Nanchang Municipality is promoting an expansion of public transportation services centered around the development of its subway system.

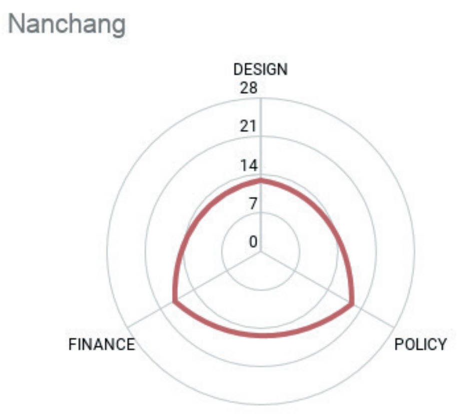
The city is leveraging Rail+Property and principles of Transit Oriented Design to finance and promote economic development and urban vibrancy.

Key to Nanchang's TOD plans have been strong urban planning, institutional coordination and designated roles for public and private stakeholders (Suzuki et al., 2015). A strong city plan informs and reassures property developers of future urban expansion, decreasing investment risks. Institutional coordination allows each private and public stakeholder to take on a specific role required to facility (for further information, please refer to Annex 03). In Nanchang, the city's Land Resource Center took on the task of acquiring and auctioning land through exercising eminent domain. The city owned, Nanchang Railway Transit Group Co. Ltd. (NRG) was established to build and operate the subway system, while a special division within NRG, staffed with former private sector employees, was created to manage the company's real estate assets.

**Highlights**

- Strong institutional coordination assigns roles to various government departments and addresses key issues of land acquisition and auction, land management, and property construction and development.

- Coordination with other transportations departments allows for integration of other public transit modes. The Nanchang Municipality coordinates with the state-owned Nanchang Bus Company to optimize bus routes and integrate them in the subway line (World Bank, 2013).




"Strong leadership in Nanchang by the mayor and vice mayors ensures interdepartmental coordination and cooperation". (Suzuki et al., 2015)

Futako Tamagawa riverside, Tokyo, Japan.
Credit: ryosukeyokoi at VSCO


Autumn Water Square, Nanchang, China.
Credit: Tripadvisor

# Recommendations

## General

*TOD should be incorporated in the city's master plan.*

Cities that have introduced TOD concepts to their master plans and are willing to support TOD principles as part of its development have shown great success in implementing a more equitable and vibrant community. Many of the recommendations and findings are could only be addressed with the appropriate political support and will.

## Design

*Raise public acceptance towards TOD principles: high density, public transit, and walkability.*

Each project should contribute to raising awareness and acceptance of TOD principles to provide a better result. Hence, before initiating any project, seeking public acceptance, at least in the zone where the project will be developed, is essential to achieving a successful outcome.

*Prioritize community economic development that contributes to the local ecosystem.*

Urban vibrancy and livable spaces are related to a flourishing economy. The impact of any project in the community is essential to avoid gentrification and to provide more opportunities to small and local businesses that contribute to generate employment opportunities and economic activity. Projects might seek to bring larger companies or food chains because they have more financial tools that will help to increase the short-term property value, but in the long-term, could not contribute to generating a sense of community and vibrancy.

*Incentivize transit connectivity and multi-modality.*

Multi-modality and transit connectivity are vital for any project that seeks a more equitable development. Multi-modality does include not only walking and biking but also the integration between systems such as BRTs, buses, subway, trains. From a user perspective, the integration must be as smooth as possible, to encourage taking multiple modes instead of only taking one that will probably take a significant amount of time due to the inconvenience of mode changing. In the end, this will motivate people to use private cars.

## Policy

*Map out the necessary stakeholders and define the role they will each play.*

TOD projects include many stakeholders from urban planning agencies, to private developers or local businesses. Understanding who they are, what their interests are and how can each of them contribute to a better TOD project is key to achieve a successful outcome.

*Ensure that TOD design and planning policies (both urban and transit) align to allow for TOD development.*

Regulations are central to any urban development project. It is imperative to have an aligned regulation that includes mixed land use, floor-area ratio, integration between transit stations and its surroundings, among other factors that contributes to better TOD projects and that supports its principles.

*Design and publish a TOD plan that communicates to bidders the procedure for applying for a TOD project or land auctions that are related to TOD projects.*

Governments need to have a different process for TOD projects as compared to urban development in other areas of their city. TOD projects have specific needs and characteristics that have to be contemplated when approving the proposal and thinking of land leases. To achieve better outcomes, this process should be as transparent as possible and bidders should be selected considering their experience in other TOD projects and how the proposal or plan supports and encourages guidelines to create a vibrant and transit-oriented community.

*Create the institutional infrastructure to facilitate TOD projects*

TOD projects touch on diverse aspects of the urban landscape - land, transportation, amenities, public space and green areas - and therefore, require coordination between different and multiple stakeholders. In order to foster and ensure this coordination, one of the key recommendations for the city of Zhengzhou is to create a division entirely dedicated to facilitating TOD projects. The role of this entity would be to liaise amongst the various government actors (planning department, transit authorities, real estate companies, among others) and serve as the first point of contact for potential private enterprises looking to bid on and navigate the steps of implementing a TOD project. Based on the case studies reviewed in this document, we recommend that this division be composed of city officials with previous experience working in either the government (for example, planning and transit departments) and real estate experts. This new division should also be responsible for pushing forward the development of TOD projects and prevent them from becoming dormant.

## Finance

*Promote R+P, not only as a financing tool for projects but also as a way to capture land value appreciation.*

Rail+Property is a novel and win-win policy that could allow the government and real estate developers to increase their revenue on TOD projects. It is crucial that responsibilities are clear, and there is support from the top political level because it will take many years to see the results of such a mechanism. Also, when signing agreements under R+P, there should be some revenue allocated for future transit expansion and some other to the operation. Real estate companies could also seek agreements that include developments next future transit expansion that are possible due to the profits of the revenue from current projects.

*Identify revenue streams.*

Revenues are not only properties rent and sale, but also includes future developments. For instance, cities with a clear master plan that includes the expansion of the transit network, could identify and propose future projects to real estate developers. There is also a profit in the future land lease that contemplates a promise for subway development next to it. Government and private actors should have every possibility to align interests in the short-term (that might not maximize profitability) but that considers future commitments.

*Evaluate how risks and returns will be spread across private and public stakeholders.*

Urban development involves many risks that need to be assessed and weighted into economic and financial models. Designing models that are fair for the public and private sector, to reduce the economic burden of the risks, could contribute to creating more profitable projects, thus increasing the revenue and future developments.

# Conclusions

TOD is an approach to urban development that contributes to a more equitable, livable, and vibrant city. We strongly believe that this is the path to achieving another level of community that includes and does not exclude people. We acknowledge that Zhengzhou is on the right path to implement TOD based on the strong political support that it is having. Still, some critical factors are missing to unleash the power of TOD across the entire city fully.

We expect this work to contribute to having a more comprehensive understanding of TOD, and also, to provide a tool and a framework to assess different projects within different cities all over the world. Our work does not expect to be the only tool, but only another one that could serve as an input for decision-makers. Also, the "TOD Clover" does not aim to compare cities, so we discourage that use. We want it to be a self-evaluation tool to understand the weaknesses and strengths of each project and city, following the idea that you could only improve if you measure. Basically, this tool could provide a baseline to later compare with.

Further analysis could be done to understand how the three aspects of the "TOD Clover" work together and if there are some that are more important than the others. Also, critical success factors might be divided into project-based or city-based, depending on whether they are just for a single project or apply city-wide. Understanding that both types of factors are important for any project, the city-wide factors remain constant through different projects in the same city, while the other ones change project to project.

## Acknowledgements

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Chapter 3.

# *Smart Sensing and Green Travel: An Innovative Green Nudge Strategy for Future Public Transit*

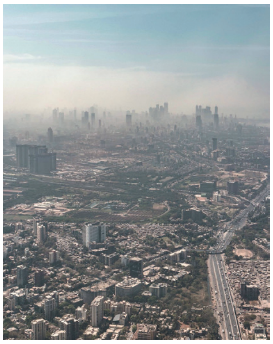
Chenab Navalkha, Geunhee Lee, Ruoming Fang, Yichun Fan

# Introduction, Context & Background

Air pollution constitutes a major global problem. Globally, indoor and outdoor air pollution cause 7 million premature deaths each year, with 4 million of these deaths attributed to outdoor, or ambient, pollution (Landrigan PJ et al. 2018). One-third of deaths from stroke, lung cancer, heart disease and other respiratory illnesses are attributed to the impacts of air pollution (Lelieveld J et al. 2015). The World Health Organization estimates that 9 out of 10 people across the world breathe in high levels of pollutants on a regular basis, and that 80% of people living in urban areas are exposed to air quality levels that are worse than the WHO's guideline limits (World Health Organization, 2018). Though air pollution has impacts across the world, particulate pollution is more heavily lowering life expectancy of those living in the developing and industrializing countries in South and East Asia (Air Quality Life Index, 2020).

This issue is especially severe for countries like China. According to the University of Chicago's Air Quality Life Index, since 2013 China has made progress in mitigating air pollution through a series of ambitious policies. Across the country, concentrations of particulate pollution were 10% lower than they were in 2013. However, significant progress remains necessary to continue to mitigate the negative health impacts of air pollution.

The transportation sector is a main contributor to urban air pollution. Of the major sources of air pollution, transportation contributes to 25% of particulate matter globally (Karagulian F et al. 2015), indicating that policies targeting transit behavior can help mitigate negative health impacts. Policy recommendations put forth by international organizations aim to simultaneously address air pollution to mitigate health effects and climate change mitigation goals, including in East Asia and China specifically. Because of the contribution of emissions from vehicular transport, a key strategy identified is to implement a shift from private vehicle transport to public transport (Air Pollution in Asia and the Pacific: Science-based Solutions, 2019; Clean Air Measures for Asia And the Pacific, 2019). Road transportation is projected to be a significant air pollution emitter and the greatest greenhouse gas contributor for the next 50 years, according to a recent study by NASA's Goddard Institute for Space Studies. Expansion of public transportation networks takes tremendous time and monetary investment. Relying on citizens' social responsibility to adopt public transit more is challenging since pollution creates a negative externality that is not fully reflected in an individual's decision-making process.



(a)

(b)

**Figure 1.** Air pollution in cities; Mumbai (a) and Zhengzhou (b). Source: photo by Abhay Singh on Unsplash (a); Wikimedia Commons (b).

Our project takes place in Zhengzhou, the capital city of Henan province, China. The seasonal variation of air pollution in Zhengzhou is huge, with winter heating leading to a substantial increase in air pollution 3 (Figure 3). For about three months of the year, the average PM2.5 level is above 100 micrograms/m . The Air Quality Life Index showed that in Zhengzhou, specifically, the change in life expectancy from 1998 to 2013 was -3.9 years (Air Quality Life Index China Fact Sheet, 2018). Due to mitigation policies, this improved by 1.5 years from 2013 to 2016, but additional efforts are needed to continue the upward trend. Though we find no studies that report specifically on health outcomes related to air quality in Zhengzhou, a 2017 study reported the annual average PM2.5 and PM10 levels to be more than 3-fold the National Ambient Air Quality Standard of China (Wang et al. 2017). That same study also identified that motor vehicles were the second largest contributor, after coal, to poor air quality in Zhengzhou.

The Zhengzhou local government has made great efforts to combat air pollution over the past years. For example, Zhengzhou has license plate-based driving restrictions, forbidding private cars to circulate one day per week on weekdays from 7 AM to 9 PM. Since 2017, this restriction was strengthened in December due to year-end air quality performance evaluation. Instead of restricting two last digits for each day, the restriction is based on an even/odd number in December, meaning half of the cars are forbidden to drive on each workday. Accompanied with one of the tightest restrictions in driving, Zhengzhou is planning to expand the subway network from 5 lines to 21 lines (Wikipedia contributors 2019). Zhengzhou is also piloting the autonomous buses on the Smart Island which is operated under Yutong, the largest bus manufacturer company in China, to investigate the potential of seamless transitions across public transits and enhance the operation efficiency of city buses through cutting edge sensing technologies. Severe air pollution problems accompanied with local government's extensive investment in public policies and public infrastructure to promote green traveling makes Zhengzhou the ideal context to implement pollution sensing application on autonomous buses and use the data obtained to make novel applications that serve as policy tools.

Therefore, for our project, we focus on developing innovative strategies leveraging smart sensing technology and behavioral nudge to reduce transportation emissions of Zhengzhou by encouraging bus mobility. "Smart City" and "Green City" are two of the most important initiatives in contemporary China. On one hand, as many as 154 Chinese cities have introduced proposals to build a smart city, according to the China Communications Industry Association under the Ministry of Industry and Information Technology. Enterprises are also eager to "go smart," envisioning great business opportunities that harness smart technologies to attract broader customers. On the other hand, due to the environmental problems associated with its rapid

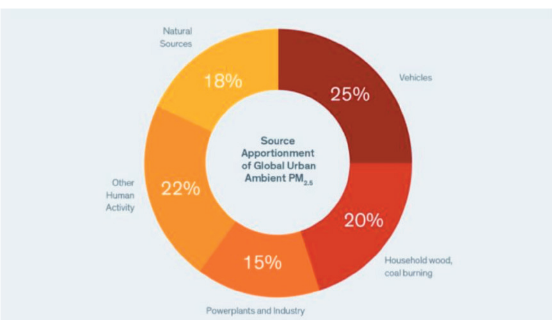



**Figure 2.** Source Apportionment of Global Ambient PM2.5. Source: Air Quality Life Index, 2020.

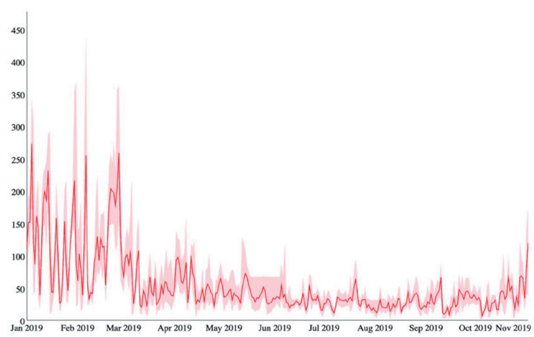



**Figure 3.** 2019 daily average PM2.5 pollution (micrograms/m$^3$) in Zhengzhou.

urbanization, the Chinese government has declared a "war on pollution" and introduced numerous green initiatives to achieve sustainable development. Faced with the double pressure from both the government and the consumers, "going green" is an unavoidable step in a company's thriving path. How to integrate urban technologies to achieve the goal of making the city "smartly" green in urban mobility is compatible with policy recommendation and business development strategies, and can effectively "hit two birds with one stone."

# Literature Review

We find three important threads of literature relevant and informative for our project designs. First, since one of the central goals of our project is to encourage green travel, we looked into the literature on the theory and application of green nudge to understand what psychological mechanisms would be effective in changing transportation behaviors. Second, we investigated the available mobile sensing projects to inform our design of sensing systems for micro-level air quality monitoring. Third, we searched for how existing literature and projects used the data obtained from smart sensing to engage and interact with users in providing informative information for citizens to self-protect against air pollution.

## Green Nudge for Green Travel

Governments around the world are increasingly relying on soft policies motivated by behavioral insights to alter citizens' behaviors in ways that improve social welfare. "Nudge" is a common type of behavioral intervention which modifies the decision-making environment (Leonard 2008; Benartzi et al. 2017). Common examples of nudge include information provision, social comparisons, commitment devices (Bhattacharya, Garber, and Goldhaber-Fiebert 2015), etc. This type of intervention is considered to be cost-effective and circumvents the drawbacks of compulsory policies, such as the coerciveness of command and control mandates and the income inequality of pricing policies. And Nudges have been shown effective at shaping a diverse range of self-beneficial behaviors including smoking cessation (Eyal 2014), exercise (Bhattacharya, Garber, and Goldhaber-Fiebert 2015), vaccination attainment (Milkman et al. 2011), education (Wozny, Balser, and Ives 2018), and citizens' application for beneficial financial projects (Hotard et al. 2019).

For nudges mobilizing environmental conservation, the incentive architecture is different since pollution is a negative externality which the emitters themselves fail to take into account. Scholars have identified two main types of motivations: intrinsic motivation and extrinsic motivation. Intrinsic motivations consist of both warm-glow (i.e., motivated by a boost in self-esteem associated with improving the welfare of others) (Andreoni 1990) and pure altruism. Since this type of incentive relies on social responsibility, it is found to be ineffective in energy conservation (Myers and Souza 2020) and green transportation encouragement (Kristal and Whillans 2019) since the incentive is usually not strong enough to support sustaining behavioral changes. Extrinsic motivation usually entails pecuniary rewards. For example, saving energy at home can also lower the energy bill. Providing nudge information with the potential for money-saving has been found to be effective in both short-run and long-run for reducing home energy consumption (Allcott and Rogers 2014; Allcott 2009). Nonetheless, a recent study using five experiments to test the effect of nudge with or without monetary incentives to shift commuting behaviors give very pessimistic results (Kristal and Whillans 2019). The authors conclude that the lack of intrinsic motivation for green travel, strong emotion attachment of car pride and the habitual rather than one-off nature of commuting behaviors are three major obstacles for mobility mode shifts. We thus conclude that an innovative strategy is required to be incentive compatible with citizens' self-interests, to cultivate bus pride and to integrate behavioral cues into the commuting trips to reinforce the nudges.

## Mobile Sensing for Smart Cities

The undertakings of smart cities are essentially driven by city-level big datasets. The reliable acquisition of such data, therefore, is an indispensable part of the smart city infrastructure. Against this background, Mobile Crowdsensing (MCS) has emerged as a promising paradigm in achieving such goals (Ganti et al., 2011; Guo et al., 2015). MCS leverages the power of sensor-enhanced devices such as smartphones and allows individual users to acquire and share sensed data in a network (Guo et al., 2015). Compared with static, centrally designed and deployed sensor networks, MCS poses several important advantages. First, an appropriately designed MCS network could significantly save the cost of sensing as the sensing nodes are, in fact, smart devices that are already present in the city. Second, for rapidly urbanizing cities, MCS is a far more scalable option while still retaining high spatial coverage and rich sensing modalities. Third, MCS is a more participatory and engaging approach, granting citizens the opportunity to actively contribute to city data and thereby combining human and machine intelligence (Guo et al., 2015).

A particular note-worthy category of MCS is mobile sensing using vehicles. Being an integral part of cities' transport network, vehicles are particularly useful for sensing characteristics and events that are closely linked with transportation. Two applications exemplify the vehicle sensing approach. Eriksson et al (2008) used accelerometers installed on taxis to opportunistically source motion data as the vehicles traverse the Boston area; processed with simple machine learning techniques, the data allowed for detection of road surface decays, also known as "potholes", with high accuracy (Eriksson et al., 2008). On the other hand, the "CityScanner" project developed by Senseable City Lab installs sensors on public-owned garbage trucks to collect air data, including particulate matter, temperature and humidity, along the road networks of Cambridge, MA (Anjomshoaa et al., 2018). By integrating vehicle sensing and cloud infrastructure, in 8 months of deployment the "CityScanner" compiled a rich dataset that enables accessible data visualization and advanced data analytics (Anjomshoaa et al., 2018).

We pinpoint vehicle sensing as particularly promising and feasible in becoming the first implemented city-level mobile sensing network, as automobiles today are quickly evolving into smart computation platforms connected to the Internet. Arguably, vehicles can also provide more sensing modalities, higher data accuracy and stability, and less power restriction than personal devices. With further developments in lower sensing costs, ubiquitous telecommunication and mobile computation, we envision that the future automobile transportation system can also serve as a crucial data source for smart cities.

## Sensing Information for Pollution Self-protection

At present, there is limited research on leveraging air quality information to impact individual response or behavior patterns. However, to inform our approach to the use of sensing technology and applications to inform citizens about self-protection from poor air quality, we identified two previous studies that aimed to influence behavior change through the delivery of real-time information about air pollution.

One study, based in Los Angeles, CA, evaluated the impact of a mobile air quality application ("AirForU") which provided users with hourly updates on local air quality (Delmas & Kohli, 2020). Users' behaviors related to engagement with the application, sharing of information with others, and willingness to take protective measures, were evaluated. The authors found that overall, the application succeeded in delivering information and education about air pollution and in improving users' protective measures. However, over the course of the 12 week study period users became less engaged with the application, indicating that that an approach not limited to a specific application may be more effective in impacting protective behaviors in a sustained manner.

A second study conducted in Mexico City, Mexico investigated the impact of a risk communication index specific to air pollution on individuals' protective behaviors (Borbet et al., 2018). Phone surveys assessed knowledge about air quality, pollution concerns and individual behaviors. The researchers found that the risk communication index itself was less influential in precipitating behavior change than personal perceptions of air quality, and that engagement in protective measures was not higher among those more vulnerable to the negative impacts of pollution. Given these findings, the authors specified a need for enhanced communications about public health impacts of air pollution and encouragement of specific protective actions to be undertaken to mitigate these impacts at the individual level.

Given the gaps between information delivery and behavior change identified in these two relevant studies, there appears to be an opportunity to leverage a more integrated Internet of Things framework and tailored smart nudging approach to facilitate individuals' green travel behaviors.

Andersen et al. (2018) put forth a framework for smart nudging that integrates sensing data into the traditional nudge approach within economics, specifically within the context of encouraging utilization of green transportation options. The main components of this "smart nudging" approach are: (1) sense, (2) analyze, and (3) inform and nudge (Andersen et al., 2018, p. 331). As specified in this paper, effective smart nudging requires personalisation to the user based specifically on "user profiles" which identify the "interests, behaviours and other characteristics of individual users" (Andersen et al., 2018, p. 335). Informed by this framework, our research and utilization of user profiles and user journeys aims to account for the disconnect in successfully impacting transit behaviors through delivery of information about air quality.

# Project Aim and Context

Due to the significance of the problem and the limited availability of low-cost solutions, we developed, with the cooperation with Yutong Group, the largest bus manufacturer and operator in China, a proposal to explore the potential of rendering air pollution avoidance an internal motivation for citizens to take green transportation (i.e., bus) more often. Yutong is an ideal collaborator for this project since their autonomous bus system has an advanced technology infrastructure, including high-speed communication, sensing technology and air purification system, to support the seamless integration of our ideas to materialed product. Furthermore, Yutong is expanding the autonomous bus to larger areas of the city, and this will likely be the mobility of the future which our system can be readily expandable to larger service areas.

With the support from our client, Yutong, our project aim to answer three questions:

*(1) Understanding the context:*
*What is the supply and demand for clean air in the Zhengzhou local context?*

Specifically, from the supply side, we wish to have a rigorous understanding of the status quo air pollution distribution patterns in different transportation environments. This will allow us to design tailored strategies to improve the air quality. From the demand side, we will investigate local citizens' knowledge of local air pollution, awareness of pollution health impacts as well as whether they change transportation behaviors on polluted days. Understanding the demand from citizens can inform the best strategy to design our interactive platform for green nudge, and whether encouraging green transportation through pollution avoidance channels will work.

*(2) Optimizing the system:*
*How to integrate sensing technology into the bus system, which can support automatic optimization of in-bus air quality through learned purifier operation?*

We designed a sensing system prototype which can cost-effectively measure the in-bus, station, and ambient air quality. The system is specially designed to take into account the wiring system and technical parameters of Yutong autonomous buses, and will provide air quality data with the time and spatial granularity to support identifying key pollution patterns. Via an empirical analysis of data, we will be able to inform the Yutong company about the air pollution "hotspots" at which installing air purifiers would achieve maximum efficiency. We also envision that our product can help Yutong automate the in-bus air purification system so that when the air pollution surpasses a certain level, purifiers at specific locations will be automatically turned on to keep the in-bus environment clean enough. In-bus high granularity air quality data could also be employed together with machine learning techniques to optimize the air purification system in the complex and shifting city transport contexts.

*(3) Interacting with users:*
*How to design a real-time pollution visualization platform based on sensing data and with green nudge communications integrated to effectively encourage green travel?*

Local citizens may not be well-informed about the severity of ambient air pollution and/or the differences across transportation environments. We identified the potential touchpoints at bus stations and in-bus environments, and made tailored designs transforming pollution education information into visual cues and integrating into the user journey of bus passengers. We are also developing pollution visualization platforms that have a near-real-time and intuitive way to inform people of the air pollution level at different places and transportation environments. After the in-bus environment gets improved, our interface designs will have large potential in encouraging green travel. Thus our user experience designs and visualization platform can benefit the citizens by reducing their personal pollution exposure, benefit Yutong by enlarging its customer base by improving in-bus air quality, and also benefit Zhengzhou local government by reducing urban congestion and pollution in the city.

Unlike other programs which mainly serve the citizens to have a better knowledge of micro-level pollution status within the city, our visualization platform will also serve Yutong company to optimize the air purifier operation. With the future vision that in-bus air quality will get improved to be much better than ambient, we instill the green nudge element in the visualization designs and the selection of interactive touch points showing the information, in the hope that more people will choose to take buses for travel as a strategy for pollution avoidance. In this sense, we innovatively propose a project prototype which has the potential to better align individual interest (i.e., health risk avoidance) with public welfare (i.e., less traffic emissions at the society level), addressing the long existing problem of the lack of incentive for people to contribute to reducing negative environmental externalities. We believe that when implementing at a larger scale all over a city, smart sensing platforms can break the vicious cycle from pollution to driving to more pollution, and help achieve socially desirable environmental outcomes through this low-cost green nudge strategy.

# Methodology

We recognized three main areas of work, which couples with our solution and system design described here. We first concern ourselves with questions on air quality and the public transport system in Zhengzhou. Studying the current government policy and citizen awareness, and learning air quality in different transportation modes gives us a clearer idea of citizens' interest in air quality and how much motivation the air quality information can produce to the commuters. As the system leverages sensing capabilities on buses to collect air quality data, we collaborate with Yutong Bus Group in installation and testing. We also engage in a data sharing relationship with Yutong and Smart Island, which points to the topic of how collaborative sensing development and shared data usage can benefit multiple stakeholders. In the third part, we ask ourselves how to effectively make sense of the data we obtained by thoughtful and intuitive interface design. In this part we work towards proposing a user journey that engages commuters and designing visualization that concisely interprets the data.

## Pollution Monitoring and Survey

In January, the team of Sustainable Urbanization Lab (SUL) went to Zhengzhou and rented four professional monitoring equipment from Fairsense to monitor the peak hour PM2.5 concentration by different transportation modes. Since the goal of the winter pollution monitoring is to understand whether air pollution varies significantly across transportation modes, the team carefully planned monitoring along three most common commuting routes into the CBD area (Figure 5 (a)). For each route, we monitored at the same time for different transportation modes, including bike, bus, taxi and subway. We made the pollution sensing on Dec 2-Dec 4, 2019 and Jan 13-Jan 17, 2020, in order to cover both clean day scenarios and polluted day scenarios and obtain more stable pollution results to make it representative. As monitoring, all team members noted down and reported the sensor number and the times at which he/she started the journey, and the time at which the journey ended.

## Sensor Deployment

We take a collaborative approach in developing air quality sensing and data visualization. For this pilot project, we identify three important stakeholders: the project team, Yutong Bus Group and Smart Island Management Committee. Each stakeholder takes key roles. Yutong Group provides the necessary hardware, including the autonomous buses and cloud-based data infrastructure, that we can equip with sensors and draw data from. The project team, on the other hand, takes charge of data analytics and visualization, which produces usage in policy and management. The Smart Island Management Committee grants endorsement to the project, arranges data use agreements with

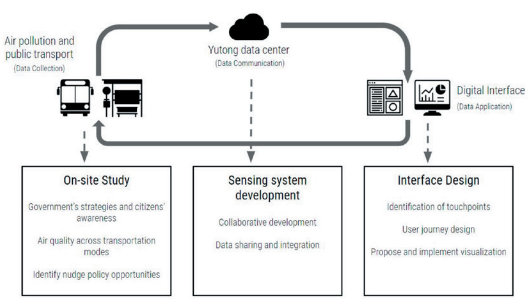



**Figure 4.** The three main components of the sensing-visualization platform, linked to the work done for implementing the system and ensuring its validity.

(a) (b)

**Figure 5.** (a) Monitoring pollution by modes in Zhengzhou. (b) Survey on the field.

all stakeholders and provides needs and feedback to the data platform. The three stakeholders therefore constitute three main parts of the system: machine intelligence (Yutong), data intelligence (project team), social intelligence (Smart Island).

In particular regarding the installation of sensors, we make active communication with Yutong Group's Smart Transit Division in conducting the work. We started by sourcing a list of major air sensor manufacturers, then proceeded to contact the manufacturers with the details of the pilot project. We also conducted meetings with Yutong and the sensor manufacturer to discuss and confirm installation details, including position of the sensors, data sockets and other physical specifications. The team also frequently coordinated the shipping of sensors, which turned out to be very uncertain in the event of COVID-19 outbreak that disrupted all industries in China.

A brief timeline of the sensor installation schedule is as follows:

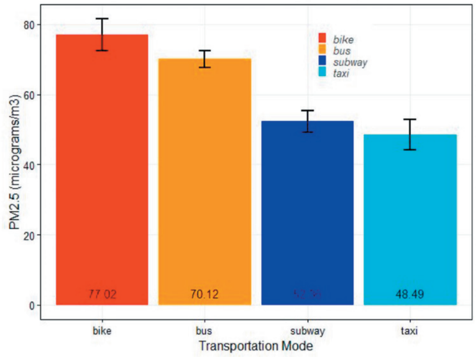
| | |
|---|---|
| **February 2020** | Sourcing of sensor choices and sensor manufacturers |
| **March 2020 - mid April 2020** | Reaching out to sensor manufacturers, confirm sensor choices, installation details |
| **April 2020** | Purchase of sensors; configuration and shipping of sensors by the manufacturer |
| **May 2020** | Receive sensors, installation and testing on buses |

**Table 1.** Sensor installation schedule.

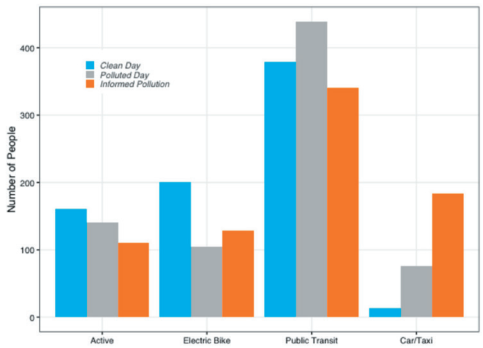
# Analysis of Findings/ Evidence

Figure 6 (a) shows the summary of the monitoring results. Compared with subway and cars, the in-bus pollution is much higher, and does not have much differences with ambient pollution (i.e., bike). Meanwhile, we find that on polluted days, people tend to decrease outdoor transportation and increase indoor ones (Figure 6 (b), comparing blue and grey bars). Recently, we see continuous technology advancement in environmental Internet of Things (IoT) applications to measure personal micro-environment pollution exposure, accompanied with the increasing demand for fine-grained air quality data. We also test what will be the transportation landscape when people are fully informed about pollution exposure in cigarettes equivalent to transportation modes (orange bars). And we find that fully aware of the pollution exposure, vehicle commuters will increase by 15% (95% CI: 11.1%, 18.5%) among all initial non-vehicle commuters. There is a necessity and opportunity to have a real-time sensing system with spatial and temporal granularity to support automatic air purification optimization, so that the in-bus air quality can be improved and the vicious feedback loop between pollution and driving can be forestalled.

Meanwhile, from the survey of local citizens in Zhengzhou, we find that local citizens are very pessimistic about the air quality in Zhengzhou. The severeness of pollution has reached public consensus. From the large scale survey with more than 3300 participants conducted by Sustainable Urbanization Lab (SUL) in July 2019, 82% of people think winter air quality is bad or terrible. Furthermore, the consequences of the pollution issue has raised great public health concerns. 73.48% of people think air pollution in Zhengzhou largely or severely impacts their health (Figure 7). On the other hand, according to our joint survey with AV group, for 99% of the 500 people we surveyed, people express that they will voluntarily take the autonomous bus more if it can protect them from local air pollution. There is strong bottom-up pressure to mitigate local pollution as well

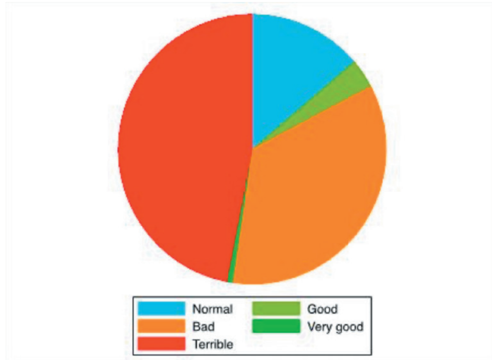



**(a)**

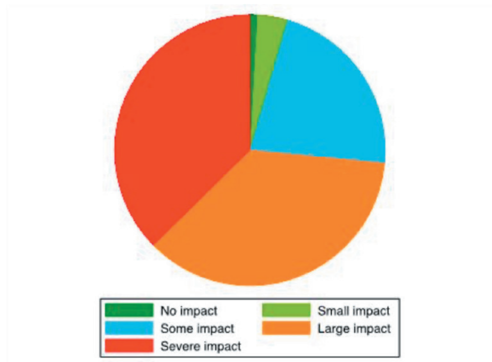



**(b)**

**Table 6.** (a) PM2.5 concentration by transportation modes. (b) Commuting choice of the non-vehicle commuters[1] in the city.




**(a)**




**(b)**

**Table 7.** (a) Perception of Zhengzhou air quality in winter; (b) Perception of local air pollution's impact on their health.

as an urgent need for the citizens to get informed about avoidance strategies available.

## Sensing system deployment progress

Due to the global outbreak of COVID-19 in early 2020, all the manufacturing and transport industries have taken a hard hit in the first half of the year, and our sensor deployment has also been delayed as a ripple effect of the macroeconomic shock. Nevertheless, the project team has still managed to maintain active coordination with Yutong in searching and procuring sensors. We were able to secure a strong tie with Cubic Sensor & Instrument Co.Ltd., one of China's major air sensor manufacturers. As production in China began to thaw from mid-March, we moved quickly to confirm with the manufacturer on the model and number of sensors to purchase and also secure technical support from the manufacturer to Yutong's personnel. We purchased the sensors in late April, and the sensor products were shipped to Yutong's campus in Zhengzhou at the beginning of May. The installation of sensors is currently in progress. The sensors are shown below:

**1.** We focus on non-vehicle users here because those commuters are more affected by air pollution, and also because we want to partially avoid the experimenter demand effect since vehicle users have a strong incentive to under report driving for social image concerns.

**Table 8.** Air quality sensors (model AQIS-1000) received by Yutong. (Credit: Mr Qin Xianjun, Yutong Bus.)

In addition, we reached a data use agreement with Yutong Bus, who will process and compile the air quality data collected by buses and relay them to the project team with a data API. Based on that, we will be able to leverage Yutong's digital infrastructure and build a lightweight database and applications for analyzing and visualizing the air quality data.

# Best Practices & Recommendation

## User Experience Designs

### *(1) Design Opportunity analysis*

For user experience design, we first defined the customer journey of the bus ride into three stages and identified various customer touchpoints in each stage.

Based on the results of the user survey, we identified design opportunities that are especially meaningful. As a result, we defined the main design opportunities as to provide real-time information before the ride, to provide playful interaction during the ride, and to provide useful information about the journey after the ride. Based on these findings in the user journey, we focused on Kiosk, the screen inside the bus, and Xiaoyu among various touchpoints.

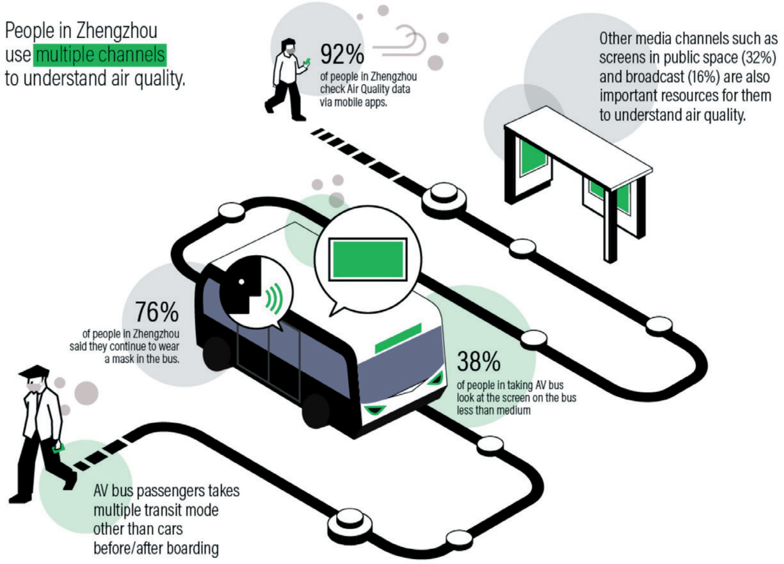



**Figure 9.** Yutong AV Bus Customer Journey.

| Stage | Target Touchpoints | Switzerland |
|---|---|---|
| Before boarding | Kiosk | Realtime update: How might we provide a better on screen information for a pleasant ambience and experience in AV buses? |
| On boarding | Indoor screen, Xiaoyu | Entertaining and useful info: How might we provide a better onscreen contents for a pleasant ambience and experience in AV buses? |
| After boarding | On-site connection | On-site connection: How might we inform passengers to be prepared with timely information of their destination? |

**Table 2.** Touchpoints

## *(2) User Research*

From the result of a user survey, we identified customer profiles and needs and then set the design direction for each touchpoint. We found that customers value greenness in their choice of public transportation and also found that we could leverage multiple screens across the customer journey as the channel for conveying information about air quality. We also found that we should be more proactive in promoting the efforts of the city and Yutong to purify the air inside the bus, as our customers are most interested in the air quality inside the bus among the various air quality information.

| Stage | Touchpoints | Value | Quote | Keywords |
| --- | --- | --- | --- | --- |
| Before boarding | Kiosk | A channel for communication of interest in the environment | "If the cost and time are the same, I will choose the most eco-friendly public transportation." | • Green travel<br>• Safety<br>• New experience • Daily routine<br>• Commuting |
| On boarding & After boarding | Indoor screen, Xiaoyu | Active promotion of air purification efforts | "I'd like to know more about the indoor air quality of the self-driving bus." | • Clean air<br>• Scenery<br>• High-tech<br>• Commuting<br>• Tour/Sightseeing |

## *(3) UI analysis*

We identified improvements can be made by analyzing the layout and information of the targeted touchpoints. From our design research, we concluded that our customers are mainly young age groups interested in the environment and are familiar with the acquisition of information through technology. Another key finding was that providing air quality information in different local levels can provide positive images of air quality purification effort while encompassing the customer boarding experience.


**Information**
- Date
- Time
- Weather
- Temperature
- Bus Stops
- Traffic
- Advertisement
- Local news


**Information**
- AI icon (Xiaoyu)
- Bus Stops
- Speed
- Battery Remain
- Routes (AR Camera)
- Indoor Temperature
- Local news

**Table 4.** Current UI design of kiosk and indoor screen.

### *(4) Design Concept 1*

Based on this, the first design concept for the kiosk aims to make a good impression as the starting point of the bus ride experience and also as the communication channel opens to the public space. The concept attempts to imprint the brand image with a clear and consistent visual cue that helps understanding information.

| | |
|---|---|
| **Scenario** | Before boarding |
| **Touchpoint** | Kiosk |
| **Key value** | Delivering AQ information intuitively & consistently |
| **Feature** | • Air Quality Indicator for multiple locations<br>• Use of visual cue for Air Quality Index |
| **Description** | Bus stations are the best places to promote the brand image to the public. Kiosks play important roles in shaping the first impression of this branding and actively conveying details on urban air quality improvement efforts by Zhengzhou and Yutong. For example, the kiosk can deliver relevant health information while providing air quality information in cities, current bus stops, and buses with easy-to-understand icons. Using indicative colors with air-related information will help people understand information intuitively. |


**Figure 10.** A-Quality Branded Kiosk.

*(5) Design Concept 2*

The second design concept focused especially on the delivery of useful information through various interactions. This concept attempts to leverage the AR Camera technology to provide information to help the customer's life and schedule, such as finding the air level of popular tourist attractions or searching for nearby places. In order to provide valuable information through playful interaction, we also tried to provide more opportunities to communicate with Xiaoyu by voice command examples at the bottom of the screen. Through these design concepts, air quality information can be represented with the consistent visual affordance to keep information intuitive, and ultimately allowing us to focus on more important information.

| | |
|---|---|
| **Scenario** | On & After boarding |
| **Touchpoint** | Indoor screen, Xiaoyu |
| **Key value** | Valuable information with multimodality |
| **Feature** | • Xiaoyu command examples<br>• AQ information using AR camera |
| **Description** | Our main target passengers are commuters who want to commute safely and tourists who want to experience new technologies. We can achieve an integrated customer experience by providing consistent branding and information used at other customer touchpoints. Using screens and Xiaoyu to make information be more useful and interesting will increase the opportunity for customer interaction. For example, the AR camera technology can be used to provide air quality of tourist attractions in the city. |

**Figure 11.** New city explorer.

## Visualization Prototype

*(1) Real-time pollution visualization platform*

A prototype which can be readily expanded to all buses in the city, showing ambient pollution, pollution at stations and pollution inside of buses with spatial distribution. Health-based green nudge communications with behavioral and psychological insights are also integrated to enhance the effectiveness of our platform for Yutong to attract more passengers and reduce urban transportation pollution.

*(2) Web interface showcase*

Despite the unfortunate delay and constraint on the project timeline that makes us unable to receive live air quality data in the stipulated time frame, we used some air quality measurements and geodata of Zhengzhou's bus stops to create a simple web application to visualize the data. The application interface shows as follows below.

This simple interactive application consists of a web map showing data points representing a subset of bus stops in Zhengdong New District, with the color of the point representing the PM2.5 measured. An interested urban manager could use the "lower bound" slider on the control panel to filter out the data points with PM2.5 concentration larger or equal than certain values. The slider scale coincides with the colored legend of PM2.5 measurement, hence making the filter more intuitive for users. We set the numerical breaks on the scale to correspond to air quality standards and render the lookup easier. Besides, considering that air quality exhibits diurnal patterns that link with citizens' living and transit routine, we also set a slider to display the sensing data measured in any particular hour. This slider helps relieve the visual pressure caused by displaying plenty of data on the screen at once, helping the manager better locate periods with high levels of PM 2.5 emission. Lastly, the information of any particular location is accessible by clicking on it, upon which a popup appears. The application, therefore, helps the urban managers to pinpoint the spatial-temporal location of severe air pollution quickly and facilitates the formulation and implementation of targeted policies.

The next iterations of this visualization platform will develop more functions and contain more plural information given the amount of data we will receive in the future. However, an invariant undergirding principle in the application design is that rather than making the decisions, the data tools should assist people in decision-making by streamlining the process of data interpretation and communication.

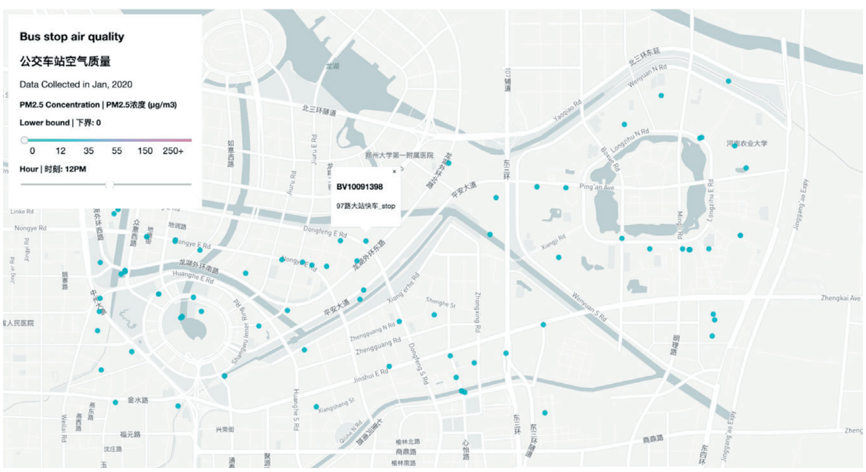



**Figure 12.** The interactive web application showing air quality measurements at selected bus stops in Zhengdong New District, Zhengzhou City. (Credit: Ruoming Fang)

## Application prospect

In the future, we envision that the visualization prototype could be implemented more widely by Yutong, and that analyses of the differential between in-bus versus outdoor air quality can be integrated into Xiaoyu air filtration systems to ensure superior air quality for bus users. On the user end, expansion of the visualization could be integrated into existing applications that are already widely used, such as WeChat. Dashboards modeled after the example provided here could share information about their exposure to poor air quality on any given transit journey and could enable users to track their historical exposure based on their transit behavior. At the city level, we imagine that air quality information at bus stops and on the buses themselves can be integrated into the transportation systems monitoring, and can inform policymakers seeking to optimize air quality and their policy designs.

Furthermore, our project has policy implications for the future green mobility strategy of Zhengzhou. The Zhengzhou government has published the Green Travel Action Plan (2019-2022) recently, which emphasizes the effort from the government level, to change from the command and control policies like driving restrictions to soft policies encouraging bottom-up voluntary adoption of green transit. Our project can assist the encouragement of green travel from at least four aspects. First, although we are piloting autonomous buses on smart island, the system can be readily expanded to all city buses to assist larger scale transportation planning. Second, the integration of sensing technology and the efforts to make pollution information transparency make autonomous buses a transit system synthesizing both advanced technology and humanistic caring. Which could effectively cultivate a sense of "Bus Pride" and encourage adoption. Third, compared with traditional green nudge policy which tries to leverage social responsibility to encourage green travel, our project innovatively leverages the interests of pollution self-protection, which could form stronger and more compatible incentives.Last but not least, in the post-covid 19 period, research in China has already shown that people have a stronger wish to purchase a car. How to provide better service to forestall the long-term decline of transit ridership is crucial for the whole nation and the whole world. And our platform designed for pollution can be used to show disinfection or other virus protection precautionary information easily.

# Conclusions

Air pollution is one of the most vexed and pernicious problems in cities today. In China, air pollution has come to prominence in recent years as an important public policy goal in the agenda of central and local governments. The transportation sector, as an integral part of city life, is naturally a major air pollution contributor whose impacts may increase substantially with continued urban expansion in China. The city of Zhengzhou, as one of the most populous cities in China and a major transit hub in the country's central region, has taken a series of aggressive regulatory measures to limit the pollutant emission from private transport, while encouraging the use of public transport through increasing the availability and attractiveness of public transport modes. Examples of public transit development include the expansion of the subway network, the electrification of the city bus fleet and the introduction of one of the first autonomous bus lines in China.

We take on the unique opportunity of maturing sensing technology and smarter bus vehicles to introduce an innovative solution that synthesizes air quality sensing and green nudge strategy to motivate citizens' use of bus transport. In a partnership with Yutong Group, one of the largest bus manufacturers in the world, and Zhengzhou municipal government, we propose and develop a system that captures in-bus and outdoor air quality on a real-time basis and simultaneously visualizes the air quality information to citizens. The system aligns citizens' private interest of self-protection from pollution and common interest of reducing city-level pollution, thereby creating a strong incentive that acts as a novel policy tool which provides an alternative route to change personal transit behavior other than the more coercive regulations.

The collected air quality data also generate additional benefits. The bus manufacturer could use the data to optimize the air filtration system on the bus and provide a cleaner environment for bus riders. Governments and urban managers could also use the data to identify points of intervention in the bus system and conduct policy analyses. These benefits will lead to further amelioration of air quality in bus, which then contribute to the green nudge by making bus transit more environmentally appealing.

In this project, we have conducted on-site studies to validate the potential of the solution, worked with Yutong in implementing the system, and designed the interactions between the sensing platform and the citizens. Through an extensive survey on local residents, we have identified strong awareness of air pollution, a pressing need for self-protection from pollution, and willingness to use vehicular transport to avoid pollution among citizens in Zhengzhou. Moreover, the air quality monitoring across various transportation modes shows that the in-bus air quality has large potential of improvement. In system development, we have successfully finished the preliminary work for sensor installation and testing on Yutong's autonomous buses despite the disruption caused by COVID-19 outbreak in China. Based on user research, we have also formulated design concepts that transform the current interfaces at buses and bus kiosks into more engaging and informative ones that delivers air quality information intuitively and promotes self-protection actions. Lastly, a simple web-based visualization prototype is made to assist urban managers in the analysis of air quality data on a broader scale.

Looking forward, our project enables multiple improvements and further research work. On the technology side, the sensing network could be expanded to include more buses in Zhengzhou, thereby providing a more complete picture of air quality in the city. The implementation of interface designs on buses and kiosks constitute another major goal to achieve. The development of air filtration system automation using the collected air quality data is also a significant progress to make. Furthermore, using the system as a venue to actually test the effectiveness of green nudge in Zhengzhou leads to explorations on the questions regarding the individual behavior responses to digital nudges consisting of micro-level, real-time environmental information. Since nudging is a relatively new policy area, the research could produce new insights that inspire more environmental and transport policy along this direction. Last but not least, this project is a pioneering effort to implement and operate a vehicle-based sensing system and data platform at city scale. It has the potential to support a new way of interaction and engagement in smart cities, where citizens connect to the city, learn about the city and act on the city. New models of living and policy making may emerge, helping cities to address challenges that include, but are not limited to the ones discussed in this report.

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