Exploring the Relationships Between Urban Form, Transportation Infrastructure, and Travel Behaviour: A Cross-City Comparison of Singapore, Beijing, Shanghai, Mumbai, Delhi, and Tokyo

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Abstract: This paper combines traffic statistics of six typical Asian cities, including population density, GDP per capita, mode share, etc., and provides an in-depth analysis of the cities' traffic situation. We summarized relationships between income, population density, transportation infrastructure, transportation policies in each city, and the mode of transportation in each area. We find that the population density in a town dramatically impacts the public transit systems, and there are significant relationships between the local travel policies and the mode share. In addition to the conclusions, we summarized the existing problems in this paper and made suggestions for future research in the field.

Keywords: urban form, transportation infrastructure, travel behavior

1. Introduction

According to the report of Global Passenger Transportation Trends in 2022, it is expected that the total revenue of global passenger transport will reach 309 billion US dollars by 2026, serving a significant market worldwide [1]. Transportation investments greatly influence where economic growth happens and how much change occurs. Modern people are used to making long-distance travels for either work or studies, resulting in transportation's critical role in current society. To further elevate people's transport efficiency and quality, analyzing existing patterns in vehicles would be inspiring.

Asia is the exemplification in this case among the continents in the world. We have selected six typical Asian cities to investigate this topic: Beijing, Shanghai, Tokyo, Singapore, Mumbai, and Delhi. We chose these cities due to the following reasons:

- All six cities have a relatively large population density and wealth base.

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- They all have experienced rapid and significant technological developments in recent decades.
- They all suffer from varying degrees of air pollution and traffic congestion due to urbanization.
- These cities are still expanding rapidly

We have analyzed specific elements in these selected cities and the existing published methods by governments. As we investigate how these elements interact and interfere with transportation, we will explore historical and current transportation patterns and suggest future urban planning. As city expansion and urbanization go on, the experience of these six Asian cities will give a solid foundation and provide advice for similarly fast-growing cities.

In this paper, we collect background information, including population, GDP per capita, mode share, etc., of case cities and conclude findings through a comparative study. We then precisely analyze the relationship between transportation and elements, including income, population density, transportation infrastructure, car ownership, and public vehicle policy in each city. Finally, we give a conclusion based on the research on the six cities.

2. Methods

This paper analyzes the everyday trends and the particularity of each city by comparing the traits of the six cities, including population, history of development, economic status, and transportation mode, to obtain the relationship between urban form and transportation development.

We collected data on urban form, transportation infrastructure, and travel behavior of the six selected cities by searching government websites and reviewing official reports and previous literature before establishing the database of various indicators, which helped us draw the main conclusions by comparing both horizontally and vertically between the six case cities.

Specifically, we used satellite imagery to map out each city's-built environment and land use patterns to obtain data on urban form. To collect data on transportation infrastructure, we used official statistics and reports from transportation agencies and local governments and reviewed relevant academic literature for the six cities.

We use each city's economic development status and population density to analyze its impact on urban form and traffic development change to compare population and GDP per capita. We compare the development process and changing situation of transportation longitudinally by analyzing the historical and cultural context. We compare the common characteristics and travel behaviors by evaluating the main traffic modes and railway line operation.

3. Findings

Table 1 presents data on the population, population density, wealth, and car ownership of the six cities examined in this study. These indicators provide critical insights for making cross-city comparisons and understanding the unique characteristics of each city's socio-economic profile. It should be acknowledged that minor deviations in the comparison may arise due to variations in the years during which data was collected.

The six cities exhibit different populations, with Singapore having the smallest population of 5.46 million [2] and Delhi having the largest population of 31.14 million [3]. Mumbai had the highest population density at 278 persons per hectare in 2014 [4] while Beijing had the lowest population density at only 13.34 persons per hectare in 2021 [5,6].

Regarding GDP per capita, the six cities show considerable heterogeneity, ranging from $5,183 to $72,800. Singapore has the highest GDP per capita, more than ten times that of Mumbai and Delhi.

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Car ownership is another critical factor in the socioeconomic status of the six cities. The average number of private cars in each city generally ranges from 100 to 400, except for Mumbai, which has a significantly lower rate of 57 vehicles per thousand residents.

Table 1: Population, wealth, and car ownership of the six cities.

	Population in 2021 (million)	The population density in 2021 (Per hectare)	GDP per capita in 2021(USD)	The number of private cars (per thousand residents)
Tokyo	14.04	61.58	49700	308 (2020)
Shanghai	24.93	39	26900	180 (2021)
Mumbai	20.74	278 (2014)	5328 (2014)	57 (2022)
Delhi	31.14	113.2	5183	355 (2010)
Beijing	21.93	13.34	27016	198 (2015)
Singapore	5.46	83.58	72800	150 (2017)

Table 2 depicts the transportation lines length per thousand people in the six cities. Mumbai has the shortest total length of the subway, which is 0.0022 km and 0.0993km, respectively [7]. This indicates that Mumbai's transport infrastructure lags that of other cities. Compared to cities with similar populations, Shanghai has the highest subway length per thousand people but has a comparatively lower length of roadway and rail transit per thousand people. This indicates that the subway is the main public transportation mode.

Regarding roadway length, Tokyo has the highest at 1.7627 per thousand people, and Mumbai has the lowest altitude of 0.0993 km per thousand people [8]. Regarding rail transit, Delhi has the most insufficient length of 0.0122km [9] while Tokyo has the largest size of 0.3360, more than 20-30 times that of Mumbai and Delhi [10].

Table 2: Number of roadway/subway/trains (km/ thousand people).

	Subway	Roadway	Rail Transit
Tokyo	0.0254(2022)	1.7627(2021)	0.3360 (2021)
Shanghai	0.0424 (2022)	0.7445 (2022)	0.0235 (2022)
Mumbai	0.0022 (2023)	0.0993 (2020)	0.0188 (2023)
Delhi	0.0112 (2021)	1.0709 (2020)	0.0122 (2022)
Beijing	0.0298 (2020)	1.0702 (2020)	0.0365 (2020)
Singapore	0.0273 (2021)	0.6158 (2021)	0.0366 (2021)

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Table 3 depicts the distribution of transportation modes in six cities, categorized into public transit (including railway, subway, bus, etc.), private car, walking or bicycling, and other methods. It is worth noting that there may be some minor deviations in the comparison due to differences in the year of data collection.

The chart shows that Singapore has the highest public transit share of all six cities, with 65% of the total mode share, while its walking/bicycling share is the lowest at 4% [11]. Mumbai has the second highest public transit usage with a share of 63% and the lowest percentage of private car share at 9%. Beijing has the highest personal car share at 30% [12]. Delhi has the largest walking/bicycle share at 33% [13]. Tokyo and Shanghai have similar percentages of private cars and walking/bicycling, with Shanghai having 9% more public transit share [14].

Table 3: Mode share percentage in the six cities.

	Public Transit	Private Car	Walking/Bicycle	Other
Tokyo (2020)	36% (railway 33%, bus 3%)	27%	23%	14%
Shanghai (2018)	45%	28%	20%	7%
Mumbai (2016)	63% (railway 43%, bus 20%)	9%	7%	21%
Delhi (2018)	48% (railway 29%, bus 19%)	19.4%	33%	—
Beijing (2014)	53%	30%	12%	5%
Singapore (2021)	65% (railway 38%, bus 27%)	23%	4%	8%

3.1. Income, Car Ownership, and Mode Choice Across Large Asian Cities

As shown in Table 1 and Table 3, approximately 150-350 cars are owned per 1,000 residents in the cities studied, and 20-30% of the residents choose private vehicles for transportation. Mumbai, however, is an exception. Mumbai has only 57 cars per 1,000 residents, and only 9% of residents travel by private vehicles.

There appears to be a positive correlation between income and private car mode share. As income levels increase, the proportion of people using private cars as their primary mode of transportation also increases. For example, in Delhi, where the GDP per capita is 5183 USD, the personal car mode share is 19.4%, which is significantly lower than other cities such as Tokyo, with a GDP per capita of 49,700 USD and the private car mode share of 27% [15] and Beijing with GDP per capita of 27,016 USD and the individual car mode share rate of 30% [16].

The relationship between car ownership and private car mode share is not clear. Tokyo, for instance, has 308 private cars per thousand people, but only 27% of residents travel by car. Delhi has a similar level of private car ownership (355 per 1,000 people) as Tokyo, but its personal car mode share is lower at 19.4%. In contrast, Beijing only has 198 private cars per thousand residents [16] but the mode share of personal vehicles is even higher than that in Tokyo. We, therefore, think that while car ownership is an essential determinant of travel mode, other factors, such as population density,

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urbanization, public transportation, and government policies, can also influence car ownership rates and obscure the correlation with private car mode share.

3.2. Population Density and Mode Choice

In typical large Asian cities, mode share strongly correlates with population density. Specifically, public transit mode share, particularly high-capacity railway systems, increases with higher population density.

According to Table 1 and Table 3, for cities with a population density of less than 100 per hectare, the proportion of private cars fluctuates at around 25%. For instance, Tokyo owns a % of personal vehicles at 27% [17], and Shanghai owns 28% [18]. As population density increases, the proportion begins to shrink. In Delhi, whose population density is 113.2 people per hectare, private car balances go down to 19.4%. In Mumbai, a city of 278 people per hectare, the ratio shrinks to 9% [19]. As for dense cities, including Mumbai, public transportation overrides private ones, with railways accounting for 63% [19], making up more than half of the city's transportation. The decrease in private cars and increment in public transportation implies the possible congestion in those cities that gives rise to the decreasing use of personal vehicles.

Among public transportation, high-capacity and high-efficiency transportation like railways predominate. The difference between the proportion of railway and bus ranges from 9 % to 30%, which shows a significant difference. The difference between these two decreases as population density increases. For example, the difference in Tokyo exceeds that in Singapore, whose population density is more than in Tokyo. The shrinking difference lies in the growing need for transportation as the population grows.

The mode share of walking and bicycling in the six cities ranges from 4% to 33%. Comparing two cities with similar population densities, there is a significant difference in the proportion of bicycles and walking. For example, Singapore has a relatively low share of bikes and walking; Tokyo's bicycle and walking are much more common than other cities. Mumbai and Delhi are similar. So, population density does not significantly impact walking and bicycle mode share.

Given the above findings, we can conclude that public transit, such as railways predominate more as the population density in a city increases. The pattern is reasonable considering that more population means more passengers using the city's public transportation system, which leads to the general preference for higher capacity and cheaper transits.

3.3. Transportation Infrastructure and Mode Choice

The more abundant the urban transportation infrastructure is, the more diverse the transportation modes will be. Transportation modes with well-equipped infrastructure also will become the first choice for residents to travel.

For Mumbai and Delhi, their road networks are insufficient, so people have fewer choices of modes, which include railway, bus, and two-wheeler. However, Mumbai and Delhi have a complete railway system, with the total length of the railway at 390 km and 348 km, respectively, which many residents choose as their primary mode choice.

For Tokyo and Singapore, because of their developed economy and advanced transportation infrastructure, people have many more choices like railways, private cars, and bicycles. Besides, Tokyo and Singapore also have complete railway lines, making railways the residents ' primary mode choice.

We can see that public transportation is highly advanced in Beijing and Shanghai. There are 28,417 km of bus routes in Beijing [20] and 1,055 km of subway lines in Shanghai. So many residents choose public transportation as their primary choice.

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3.4. Public Policies, Car Ownership, and Mode Choice

3.4.1. Mumbai

To ease congestion and improve road safety, the Mumbai government has imposed traffic bans on certain types of transportation. However, due to the different levels of development in the northern and southern parts of Mumbai, there are different rules for each section. For north Mumbai, heavy vehicles, except luxury buses and those carrying essential commodities, are prohibited from 8 am to 11 am and 5 pm to 11 pm. Under the Motor Vehicle Act of 1988, heavy vehicles entering the city are subject to a fine of Rs 2000. In South Mumbai, the rule is more stringent due to the dense population; all heavy vehicles except those carrying essential commodities are banned from 7 am to 12 am [21]. On the Eastern Freeway, the ban is in effect around the clock. It is even illegal for three-wheeler vehicles to enter South Mumbai.

The Mumbai government also actively promotes the use of public transport. To improve traffic and transportation facilities, the Mumbai Metropolitan Region Development Authority, with the assistance of the World Bank, completed a comprehensive Transport Study in July 2008 under the Mumbai Urban Transport Project, which recommended a planned phased implementation of a 435 km metro network, a 1740 km highway network, and a 248 km suburban railway network by 2031 [22,23]. Due to its high population density, comparatively low average income, and Mumbai's distinct geography as a narrow, island-like peninsula, residents of this bustling metropolis heavily rely on public transportation, accounting for 63% of the mode share. Most of the population does not own a private car: 57 out of every 1,000 residents do. This preference for public transit is also reflected in the 9% of car mode share in Mumbai.

3.4.2. Delhi

New Delhi is the second most populous city in India. People use private cars, public transport, and bicycles or walking as their primary modes of transportation. For personal vehicles, the number of individual cars registered in the city exceeded 2.6 million by the end of March 2015. In Delhi, there are about 335 private cars per 1,000 residents. According to statistics, 7,046 electric vehicles were sold, accounting for 16.8% of total vehicle sales [24]. The rise of electric cars has been helped by the "Change Delhi" policy, which aims to promote the environmental benefits of electric vehicles and make the capital city pollution-free [24]. The success of this policy can be attributed to the "three I" model - incentive, innovation, and inclusion [24]. The incentive is the subsidies provided by the government to encourage citizens to buy electric vehicles; Innovation refers to continuous innovation and improvement of infrastructure; Inclusion is about bringing more stakeholders, especially women, to the forefront of electricity transformation. In addition, to ease the traffic pressure and congestion caused by motorcycles, the government issued a notice in February 2023, which banned motorcycles from the range, with violators subject to fines or severe imprisonment. But citizens do not like the idea because many are doing this to make a living.

3.4.3. Singapore

Singapore is densely populated, reaching an average of 83.58 people per hectare, according to 2021 statistics [25]. To meet the travel needs of residents, the Singapore government has established a comprehensive public transport system. Singapore's Mass Rapid Transit (MRT) system is the most complete and developed globally. By 2021, there are already 113 subway stations, reaching 0.0273km per 1,000 people, which results in 65% of Singapore residents traveling by public transport [26]. The Singapore government has strict policies to limit the number of private cars. First, the cost of owning a car in Singapore includes the price of the vehicle, Excise Duty, Goods and Services Tax (GST)

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registration fee, Additional Registration Fee (ARF), and maintenance costs. More importantly, cars in Singapore must purchase a Certificate of Entitlement (COE) issued by the Singapore City Council to successful residents through a quota bid. The price of COE is related to the price, type, and displacement of the vehicle and is relatively high in terms of body. As a result of these restrictions, Singapore has only 150 cars per 1,000 people, with the proportion of car-only commuters decreasing from 24.8% to 23% between 2010 and 2021 [26].

3.4.4. Shanghai

As a densely populated city, Shanghai has implemented public policies to avoid congestion on the road, promote sustainable transportation, and control car ownership. The city's license plate auction system limits the number of new cars registered yearly, with only 100,000 new plates being auctioned off in 2021 [27,28]. Additionally, road tolls and vehicle use restrictions have been implemented to discourage driving. Despite this, car ownership remains high among wealthier residents, with private car ownership reaching 3.62 million in 2021, and 28% of residents travel by private car. To encourage alternative modes of transportation to reduce road and air pollution congestion, Shanghai has invested heavily in its public transit system, with over 1000 kilometers of metro lines and more than 1,500 bus routes. This has led to a significant increase in the use of public transport, which was used by more than 4.4 billion people in 2020, with 45% of residents choosing public transportation as their mode of travel. In addition, Shanghai has implemented a bike-sharing program that has increased recently, with more than 450,000 shared bikes available for use in 2021 [28]. In summary, these public policies support and control the urban transportation system, where different modes operate, allowing people to choose the appropriate mode of travel according to their needs.

3.4.5. Beijing

The expansion of the urban population and urban economic activity in Beijing has led to the overloading of public transport infrastructure. This increases traffic congestion and causes severe financial loss as people must spend more time dealing with traffic congestion. The private car ownership in Beijing in 2015 was 198 per 1,000 people compared with the national average of 122 per 1,000 persons, indicating that the transit demand far exceeds transit capacity [29,30]. Beijing has implemented several policies to relieve the traffic congestion problem. Except for government and emergency vehicles, all cars are restricted by the last number of a license plate: The tail number of motor vehicle license plates (including temporary license plates) is divided into five groups, and cars with two individual tail plates are restricted on a specific weekday per week, and the specified days are changed every three months [31]. This regulation could reduce vehicle emissions and improve air quality in Beijing. However, the policy may need to be more effective because people may have two or more cars with different license plate numbers, or they may push off their plans that are restricted to another next to deal with the inconvenience of the policy. However, since Beijing has well-developed subway lines, it would encourage people to commute by subway, which not only reduces traffic congestion and saves time but also reduces the emission of pollutants.

3.4.6. Tokyo

Tokyo has a balanced mode share due to the friction between private and public transportation. Tokyo has strict regulations on private car ownership. To own a private car in the city, one must have a fixed parking space and undergo a government-mandated safety and maintenance inspection every two years. An average parking space rents for $221.77 to $443.54. The compulsory maintenance inspections, called shakedowns, cost about $443 each time [32]. These two costs add up to a relatively high expenditure. Payments and strict rules have resulted in the city having a low rate of private car

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ownership compared to other cities of similar wealth and urban form. People in Japan who use small vehicles, including motorcycles, would also have to pay an additional tax of $44.32 per year, the price of which has already been cut by 60% by 2021 [32]. Aside from private cars, the railway is the most critical transportation mode operating in Tokyo. The railway system in Tokyo includes the underground and JR lines, each carrying millions of passengers each year. The friction of taking the railway lines in the congestion rate in Tokyo has remained high at around 170% in recent years, ranking first in Japan. In Tokyo, the mode choice of the railway is high at up to 36%, overriding any of the selected case cities.

4. Conclusion

This paper examined the relationship between income, urban form, public policy, car ownership, and mode choice in six large Asian cities.

Income, urban form, public policy, car ownership, and transportation patterns are essential to the growth and evolution of cities. Income determines the status of urban GDP, seen from the prospect of urban economic development, and then extended to the industrial layout. Public policy can tell cities' development plans in recent years, the future, and the city's positioning. The traffic situation and urban form constitute the condition of the urban living circle, which can reflect whether the urban infrastructure is perfect. We take six Asian cities as cases to compare these factors and conclude.

4.1. Population and Density

The population density within a city has a more significant impact on the dominance of public transit systems than the population itself. The need for efficient transportation solutions becomes more pressing in densely populated areas as individuals are concentrated in a limited space. Public transportation systems, such as railways, are, therefore, particularly well-suited for densely populated urban environments as they can accommodate and transport a substantial number of passengers rapidly and effectively. Furthermore, these systems occupy limited urban space more efficiently than roads and highways, which is particularly critical in densely populated cities. However, it is essential to recognize that population density, while a critical factor, is not the only factor that determines public transportation use patterns. Other socioeconomic factors may occasionally act synergistically with population density, leading to inconsistencies between population density rankings and public transit mode shares.

4.2. GDP and Car Ownership

It can be concluded that there is a positive relationship between income and the proportion of trips taken by private cars. As income levels rise, the percentage of people using private cars as their primary mode of transportation also increases. This is easily understood and justified because higher incomes mean that families have a better financial base and are therefore willing to choose private transport to travel. However, there is no strong relationship between private car ownership and private car mode share. This can be attributed to various other factors, such as population density, urbanization, urban infrastructure, and government policies, which affect people's choice of travel mode.

4.3. Transportation

The six Asian cities mentioned in this paper have large populations and are increasing in transportation, with residents having various transportation options. These cities are well-developed in public transit and networks, with Beijing, Shanghai, Singapore, and Tokyo having separate cycle lanes. In addition, the number of private cars in Beijing, Shanghai, Mumbai, and Delhi has increased significantly due to rising incomes. However, the governments of the six cities have all proposed policies to make efficient use of public transport and reduce the use of private cars. Due to the large population, Beijing, Shanghai, Mumbai, and Delhi have severe traffic congestion, which challenges the environment.

4.4. Limitations and Future Research Suggestion

Despite the analysis presented in this paper, some limitations must be acknowledged. Firstly, the research only focused on six major cities in Asia, which may not be representative enough of the entire Asian region. Secondly, the data used in this research are found from different sources or are from other years, which may interfere with the accuracy of the conclusion drawn. Finally, the study only examined the relationship between urban form, transportation infrastructure, and mode share. Still, other factors, such as cultural factors, may influence travel behavior but are not considered.

Future research should use data that are more consistent with each other and also consider including more factors in the analysis. It's also possible to include comparisons between cities on different continents. Despite these limitations, this research provides valuable insights into the relationships between urban form, transportation infrastructure, and travel behavior and sets the stage for further study in the relevant area.

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