# What is the relationship between the distribution of parking facilities and the local traffic in Kwun Tong, Hong Kong?

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# 1 Table of Contents

# 2 Introduction

## 2.1 Abstract

Since the industrialisation of Hong Kong (HK), the territory has observed a steady increase in car ownership, while the growth rate of the total amount of parking spaces has decreased ("Transport Department", 2021), resulting in a shortage in parking supply. With HK being one of the busiest freight and container hub ("HKTDC Research", 2021) and being one of the most densely populated areas ("Census and Statistics Department", 2021), the development of an efficient transportation system is paramount to the long-term sustainability of the logistics industry. With the vehicular speed in urban areas declining ("Legislative Council Secretariat", 2014), traffic congestion decreases the throughput of products and services, exacerbates air pollution, and worsens the quality of life of citizens (Arnott and Small, 1994). Therefore, this investigation aims to provide a more solid understanding of the relationship between the spatial distribution of parking spaces and the local traffic in urban areas of HK, so to build a more resilient and sustainable transport system.

## 2.2 Literature Review

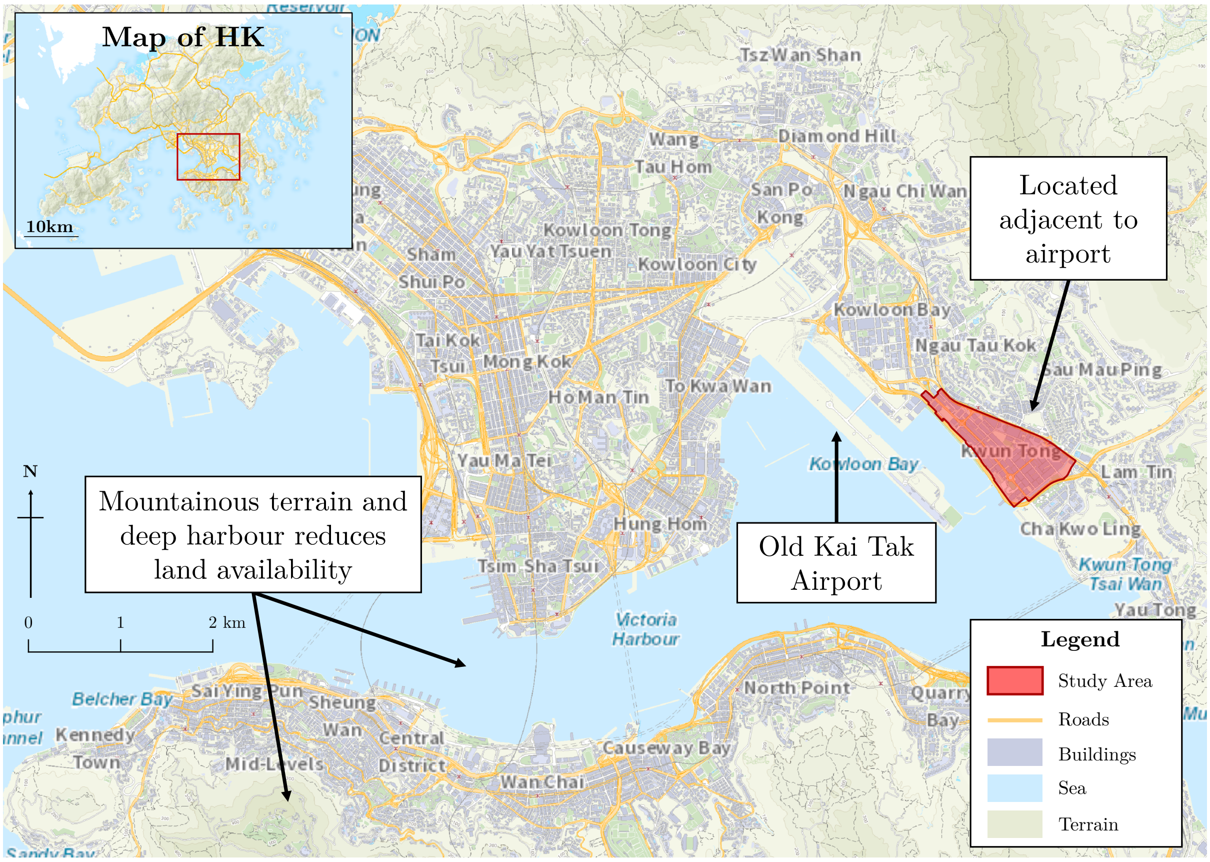
According to the Transport Advisory Committee (20??), traffic congestion is one of the most important urban issue in HK. Many researchers have compared traffic congestion to fluid dynamics, outlining the three fundamental components, including flow, the number of vehicles passing through a point per unit time; speed, the distance covered per unit time; and density, the number of vehicles occupying a road segment per unit distance (Salter, 1976; Gaddam and Rao, 2018). Although multiple attempts have been made to relate speed and density (Greenshields, 1935; Drake et al., 1967; Wang et al., 2010), it has been widely accepted that traffic congestion is characterised with high density and low speeds (Bovy and Saloman, 2002).

It has historically been trivial to quantify traffic congestion (Aftabuzzaman, 2007). One of the methods developed is the Roadway Congestion Index (RCI), which the ratio between the mean time delayed and the theoretical free-flow travel time (Schrank et al., 1994). Although the measure is widely implemented in the U.S., researchers have argued that the measure is inapplicable to public transport heavy cities (Levinson and Lomax, 1996), which is the case for HK as 90% of the population uses public transport ("Legislative Council Secretariat", 2016). Another measure adopted by the U.K. and Japan is the volume-to-capacity (V/C) ratio, which is calculated by the quotient of the measured traffic volume and the maximum design volume and are often classified into different traffic behaviour categories (Lindley, 1987). Despite the measure offering great scalability, since fundamental parameters are not accounted for, some researchers have criticised using V/C as a measure of traffic congestion (Gordon et al., 1997; Hamad and Kikuchi, 2002). With a variety of different measures developed, researchers have argued that the direct measurement of traffic speed is arguably the simplest, least biased, and most representative method of quantifying traffic congestion (Wardrop, 1952; Ye et al, 2006; Cvetek, 2021). Speed can be measured directly with cameras or estimated from time-occupancy, the percentage of time occupied by a vehicle, from inductive loop detectors or manually (Ulberg and McCormack, 1988; Arasan and Dhivya, 2009).

The distribution of services is often expressed by the extent of which geographical features are clustered or evenly spread out. Because drivers have the incentive to park at locations closest to their destination (Parmar et al., 2020), insufficient off-street parking spaces often cause drivers to resort to curb-side illegal parking, reducing the road capacity and increasing road accident risks (Tong et al., 2004). On the other hand, an overabundance of parking space can also cause drivers to cruise around the area in search for lower costs, resulting in a lower vehicular speed and the occupation of road space (Shoup, 2006). Therefore, multiple parking strategies and models have been developed in order to ensure an evenly distributed level of service, such as the Second Parking Demand Study in HK (Wong et al., 2000; Lau et al., 2005).

The distribution of facilities can be measured using the Nearest Neighbour Index (NNI), which is the ratio between the observed and expected mean Euclidean distance (Pinder and Witherick, 1972). Although the index provides an excellent general outlook on the inequity of services, the assumptions that facilities are fully interconnected with no friction of distance is highly unreasonable (Wang and Lou; 2005). With the need of pinpointing regions with inadequate supply of facilities on a microscopic level increasing, researchers have developed the two-step floating catchment area method (2SFCA), which involves summing up distance-decayed supply-to-demand ratios (SDR) surrounding the survey point (Wang and Luo, 2004). Since 2SFCA incorporates the both the aspatial utilisation of the service and the spatial demographic patterns, 2SFCA can effectively represent the real-life preferences of users and therefore has gained widespread interests in applications such as the measurement of accessibility in healthcare services (McGrail, 2012; Chen and Jia, 2019).

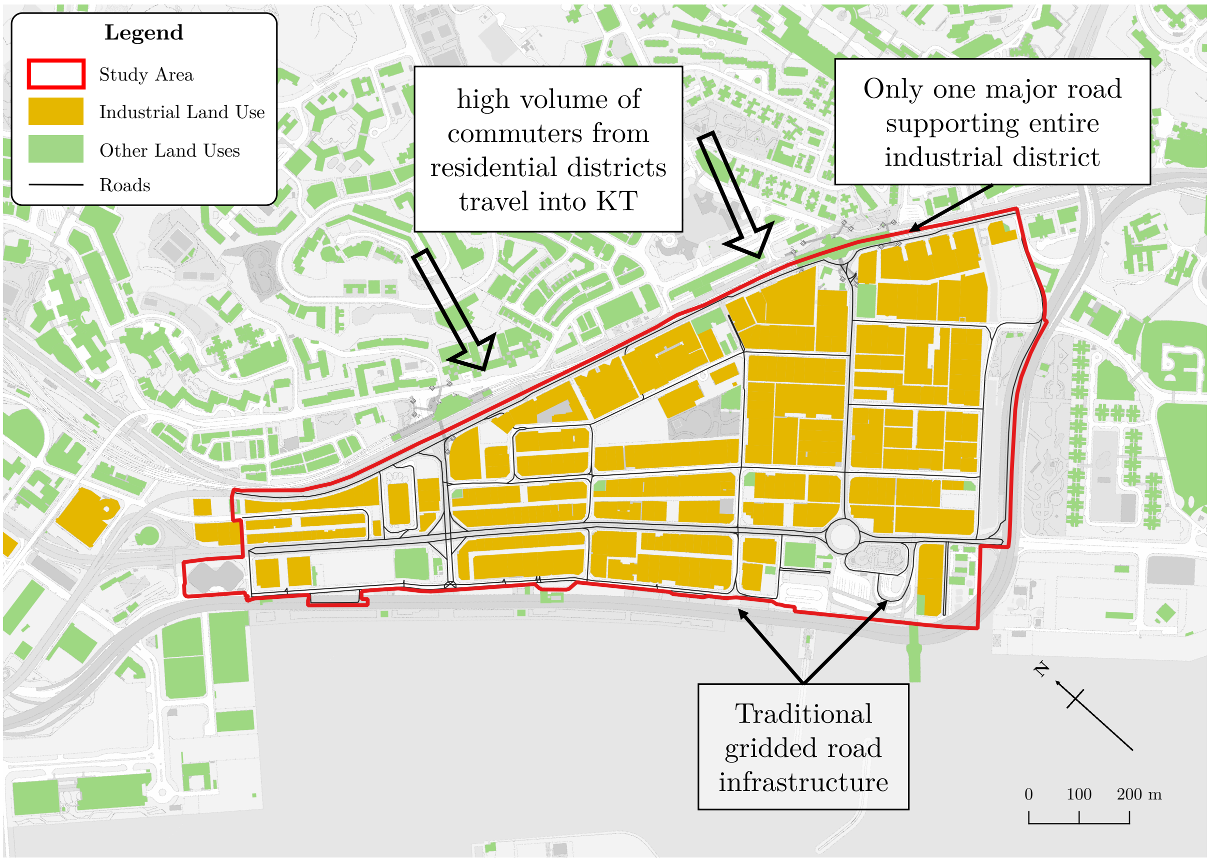
# 3 Geographical Context




**Map 1**. The location of the study area with reference to HK. (Hong Kong Geodata Store, 2021)

Due to the unique mountainous geography of HK, with land availability being highly contested and limited, land developers often construct tall buildings in order to maximise their profit. As a result, due to the densely populated nature of HK, the demand for transport services is exceptionally high, causing severe traffic congestion.

In the early 1950s, HK is a major manufacturing hub for the Greater Asia. To fulfil the growing industrial needs, Kwun Tong (KT) has been designated as the first industrial zone of HK (Kwun Tong District Council, 2015). As KT is within close proximity to the then-airport (see Map 1), it allowed raw materials to be rapidly imported and products to be efficiently exported, generating large volumes of traffic (Lai and Dwyer, 1965).




**Map 2**. The road infrastructure and land use of the study area. (Hong Kong Geodata Store, 2021)

In order to boost economic productivity, KT has been designated as a satellite city (Scott, 1982), where industrial zones and residential areas are clearly segregated from each other, as shown above. Although distinct functional zones can increase the quality of life in residential neighbourhoods and allow industrial activities to be centralised, high volumes of cross-commuting occur during peak hours, resulting in heavy traffic stresses (Merrilees et al., 2013). Furthermore, due to the traditional gridded road layout, the high amount of traffic junctions and intersections causes traffic flow to be frequently interrupted. Coupled with the fact that the area has the highest population density across all districts of HK ("Census and Statistics Department", 2016), KT is renowned for its heavily congested traffic, with bus journey speeds as low as 1.32km/h during peak hours (Tse and Wong, 2021).

## 4 Hypothesis

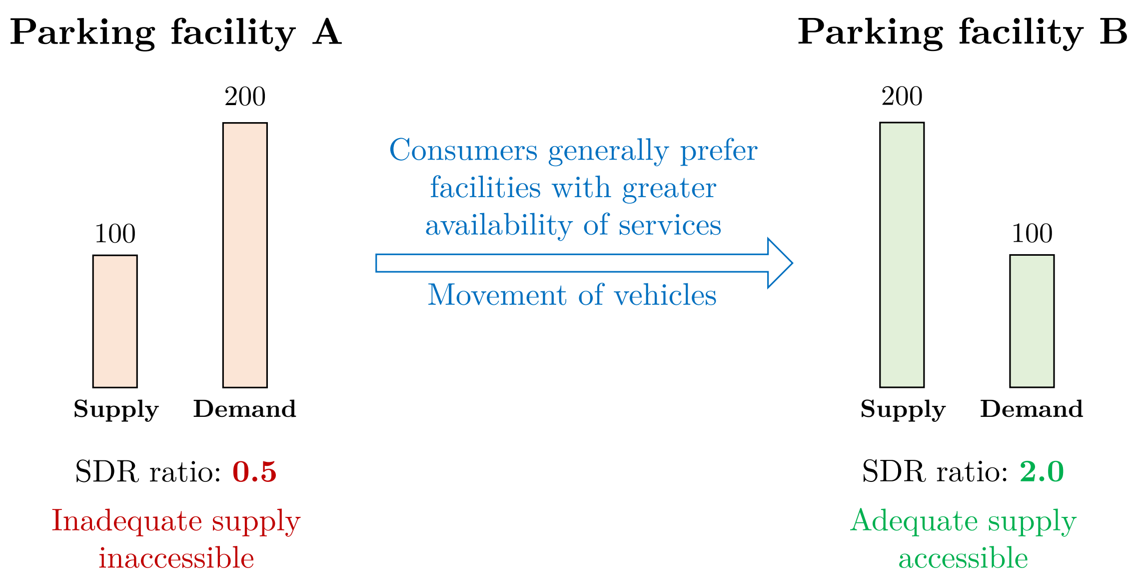



**Figure 1**. Demonstration of the movement of vehicles to areas with greater parking accessibility.

As shown above, where there is an imbalance in SDR, drivers tend to move towards areas with greater supply in parking spaces. While it is commonly believed that areas with adequate supply in parking facilities can alleviate traffic congestion, several researchers have pointed out the excess of parking supply can instead worsen traffic congestion. The reason for this phenomenon goes by that with a wide spectrum of parking spaces available, drivers are willing to constantly circle around the area in search of better parking prices (Millard-Ball et al., 2020). Since cruising behaviour often involves frequent lane-changing and abrupt changes in vehicle acceleration, it essentially forms a mobile stream of slow-moving traffic queue, thereby worsening traffic congestion (Zhu et al., 2020). Conversely, in areas with inadequate parking supply, drivers are less likely to bid for lower parking cost at the expense of losing the opportunity to park, therefore reducing cruising and lead to smoother traffic (Shoup, 2006).

Therefore, the following set of hypotheses will be tested in this investigation:

Null hypothesis ($H_0$): There is no correlation between the relative magnitude of traffic congestion and the accessibility to parking spaces.

Alternative Hypothesis ($H_1$): There is a negative correlation between the relative magnitude of traffic congestion and accessibility to parking spaces.

# 5 Methodology

To assess the correlation between the independent and dependent variables, the accessibility will be first computed by processing the locations of all roads, buildings, and parking facilities through a modified version of Ga2SFCA method with QGIS[1] and Python[2], which is detailed in Section 5.1. An on-site survey will then be performed to measure the traffic congestion, detailed in Section 5.2. Finally, both variables will be compared to validate the alternative hypothesis using the Spearman Rank Correlation Coefficient (SPCC), detailed in Section 5.3.

[1] An open-source geographic information system (GIS) software, available at: https://www.qgis.org

[2] A general-purpose programming language, available at: https://www.python.org

## 5.1 Accessibility

### 5.1.1 The Gaussian-based two-step floating catchment method (Ga2SFCA)

As explored in the hypothesis, since the utilisation of parking services is heavily influenced by the SDR of the location, the accessibility at location $i$ can be expressed by the sum of SDRs of every facility $j$:

$$A_i = \sum_j \frac{S_j}{D_j} \tag{5.1.1.1}$$

where:

| | |
|---|---|
| $A_i$ | Accessibility to parking facilities at location $i$ |
| $S_j$ | Supply of parking facility $j$ |
| $D_j$ | Demand of parking facility $j$ |

However, the equation above infers that each parking facility has an equal probability of being selected by the driver, which is inherently untrue. In fact, because transport incurs some form of cost such as time, drivers often have to overcome the friction of distance using additional resources, consequently, the attractiveness of a facility is attenuated at increasing distances (Huff and Jenks, 1968).

The distance decay effect is often accounted mathematically by multiplying the attractiveness by some monotonically decreasing distance decay function. The most commonly used function is Gaussian-based (Dai, 2010; Luo and Whippo, 2012; Tao et al., 2020), defined by:

$$f(d, d_0) = \begin{cases} \dfrac{e^{-\frac{1}{2}\left(\frac{d}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} & \{d \leq d_0\} \\ 0 & \{d > d_0\} \end{cases} \tag{5.1.1.2}$$

where:

| | |
|---|---|
| $d$ | Distance between location and facility |
| $d_0$ | Maximum catchment distance |

Since the demand of a parking facility follows distance decay effects:

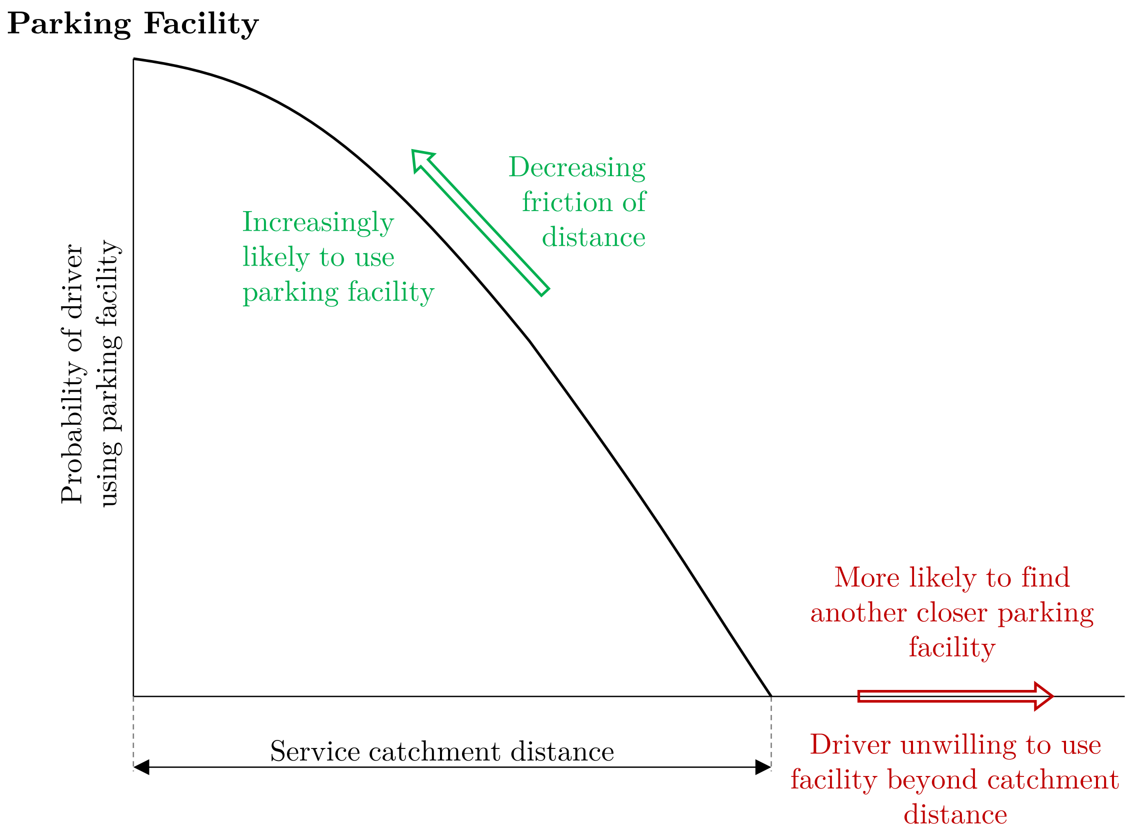



**Figure 3**. Demonstration of the distance decay effects on the supply of parking facilities.

The effective supply is often adjusted with the distance decay function (Wang et al., 2021), hence Equation 5.1.1.1 can be better represented as:

$$A_i = \sum_j \frac{S_j f(d_{ij}, d_i)}{D_j} \tag{5.1.1.3}$$

where:

| | |
|---|---|
| $A_i$ | Accessibility to parking facilities at location $i$ |
| $S_j$ | Supply of parking facility $j$ |
| $f$ | Distance decay function, as defined in Equation 5.1.1.2 |
| $d_{ij}$ | Distance between location $i$ and parking facility $j$ |
| $d_i$ | Service catchment distance of location $i$, by driving |
| $D_j$ | Demand of parking facility $j$ |

Since the distance decay effect also applies for the demand:

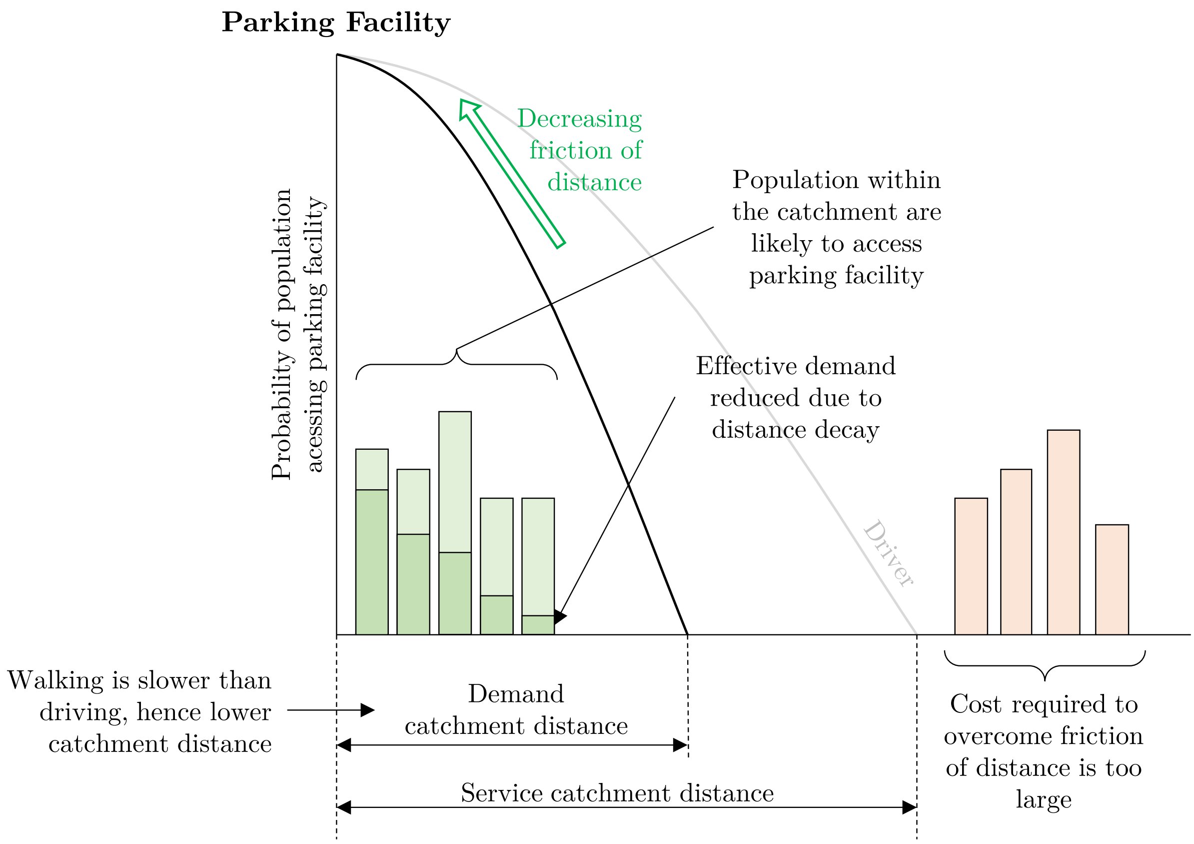



**Figure 4**. Demonstration of the distance decay effects on the demand of demand nodes.

The demand of a facility can be represented by the sum of distance-decayed effective demands at every demand node $k$ surrounding the facility $j$. This yields the final equation of Ga2SFCA, which accounts for both the aspatial utilisation and spatial effects (Wang et al., 2021):

$$A_i = \sum_j \frac{S_j f(d_{ij}, d_i)}{\sum_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

where:

| | |
|---|---|
| $A_i$ | Accessibility to parking facilities at location $i$ |
| $S_j$ | Supply of parking facility $j$ |
| $f$ | Distance decay function, as defined in Equation 5.1.1.2 |
| $d_{ij}$ | Distance between location $i$ and parking facility $j$ |
| $d_i$ | Service catchment distance of location $i$, by driving |
| $D_k$ | Demand at demand node $k$ |
| $d_{jk}$ | Distance between parking facility $j$ and demand node $k$ |
| $d_j$ | Demand catchment distance of parking facility $j$, by walking |

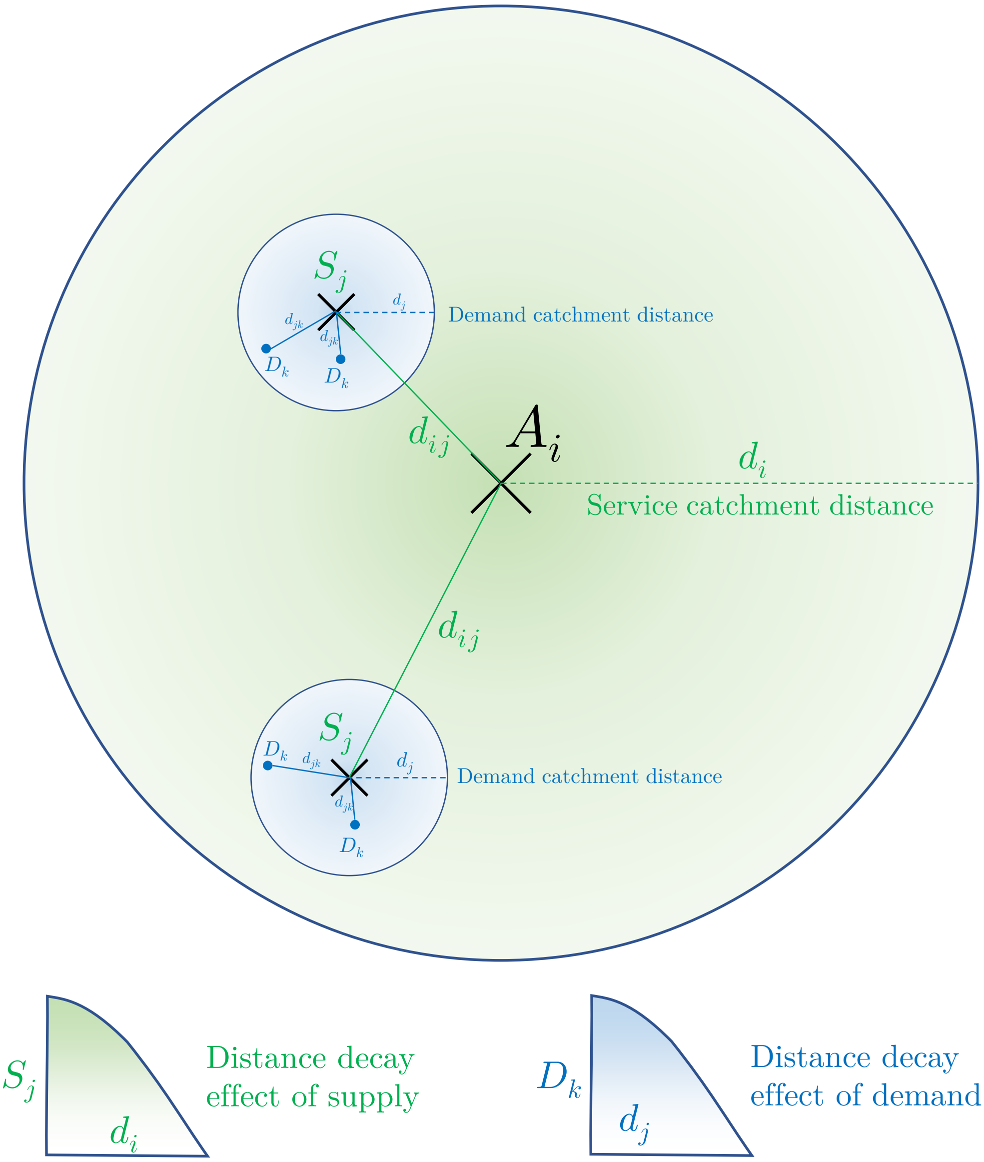
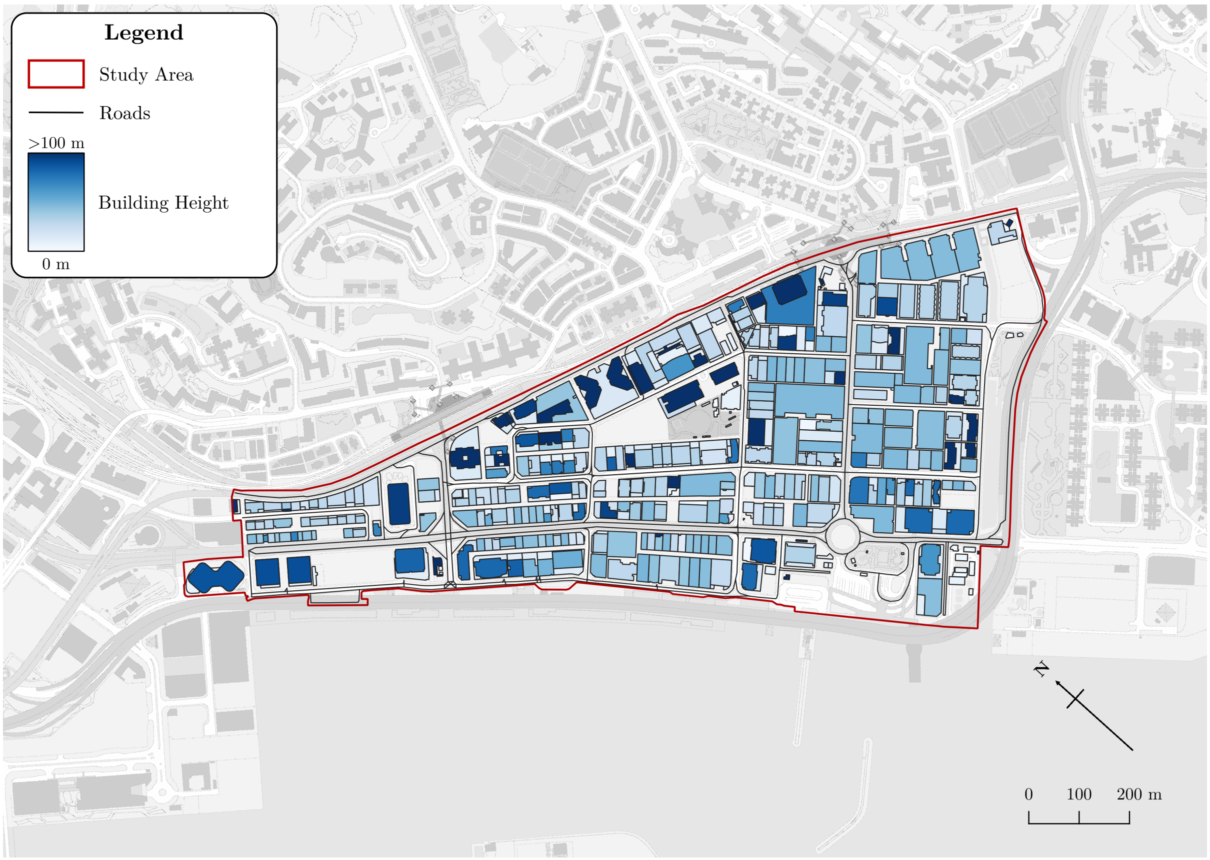



**Figure 5**. Visual representation of the Ga2SFCA method.

### 5.1.2 Quantification of demand

$$A_i = \sum\nolimits_j \frac{S_j f(d_{ij}, d_i)}{\sum\nolimits_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

In order to obtain the demand at every demand node $k$ required for Ga2SFCA, a digital "iB1000" map is first downloaded through the HKMS2.0 portal ("Lands Department", 2021), and all buildings are then extracted using QGIS, displayed below:




**Map 3**. All buildings and their heights. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

Since the demand to parking facilities is closely correlated to the gross floor area (GFA) of the building, the relative demand at each demand node $k$ is proportional to the product of the estimated number of floors and the area of each floor:

$$D_k \propto \text{GFA} = A_{floor} \left\lfloor \frac{h_{rooftop} - h_{base}}{\overline{h_{ceiling}}} \right\rfloor \tag{5.1.2.1}$$

where:

| | |
|---|---|
| $h_{rooftop}$ | Height of the roof of the building (mPD[3]) |
| $h_{base}$ | Height of the base of the building (mPD[3]) |
| $\overline{h_{ceiling}}$ | Average ceiling-to-ceiling height of a building, which is 3.0m (Cheung, 2019) |
| $A_{floor}$ | Area of each floor ($m^2$) |

The list of buildings and their GFAs are listed in the Appendix.

[3] mPD refers to the number of metres above the Hong Kong Principal Datum (HKPD), which is a standardised Ordanace Datum similar to “metres above sea level” (AMSL)

### 5.1.3 Quantification of supply

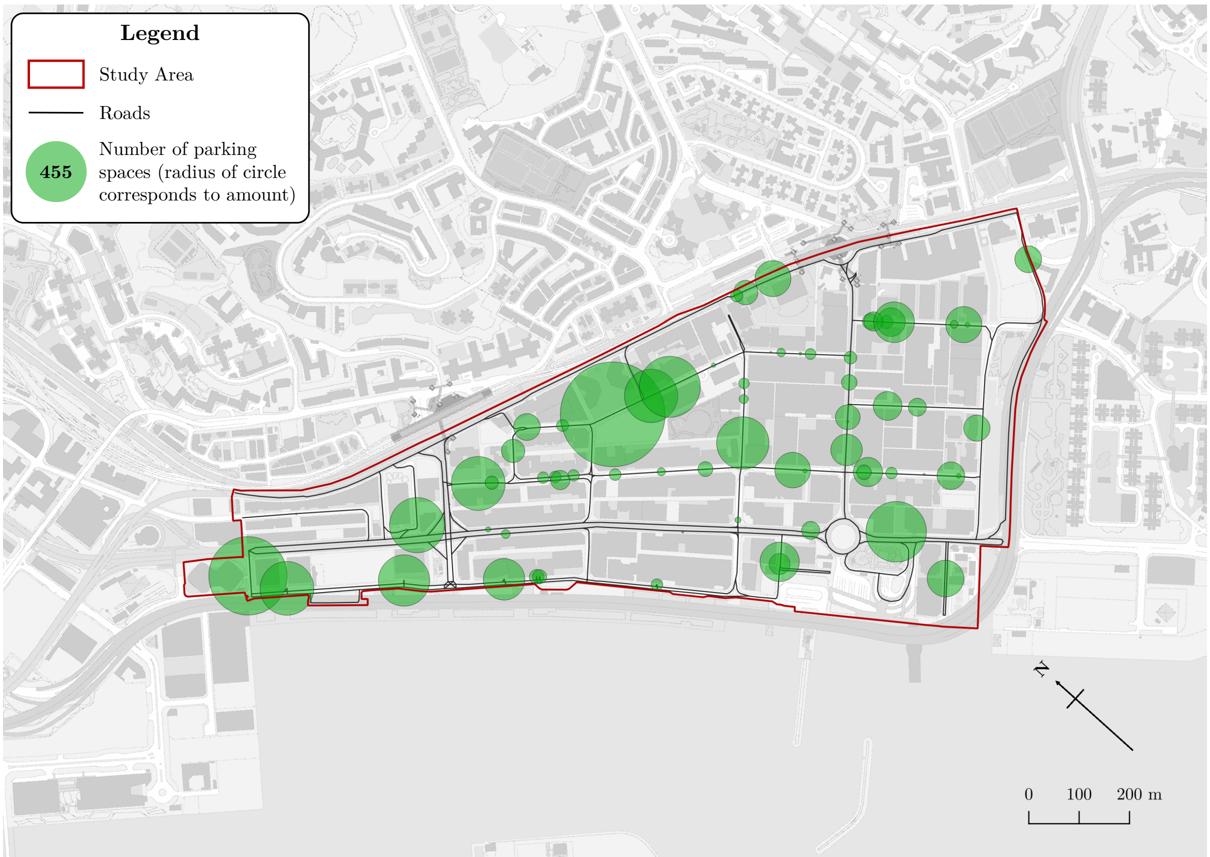
$$A_i = \sum\nolimits_j \frac{S_j f(d_{ij}, d_i)}{\sum\nolimits_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

Since the exact number of parking spaces is not publicly available, the supply ($S_j$) is often estimated using parking standards (Wang and Liu, 2014). Since 1965, HK has maintained a set of specifications for newly constructed buildings known as the Hong Kong Planning Standards and Guidelines (HKPSG), of which, the recommended number of parking spaces $N$ for buildings classified as business use ("OU/B") are (Planning Department, 2021):

$$S_j \approx N = \begin{cases} \left\lfloor \dfrac{\text{GFA}}{675} \right\rfloor & \{n \in \text{I} \cap \text{O}'\} \\ \left\lfloor \dfrac{\text{GFA}}{175} \right\rfloor & \{n \in \text{O}, \text{GFA} \leq 15000\} \\ \left\lfloor \dfrac{\text{GFA}}{175} + \dfrac{\text{GFA} - 15000}{250} \right\rfloor & \{n \in \text{O}, \text{GFA} > 15000\} \end{cases} \tag{5.1.3.1}$$

where:

| | |
|---|---|
| GFA | Gross floor area of the building (m$^3$), which is obtained from Section 5.1.2 |
| $n$ | Specific land use of the buildings, type: 'I' (industrial use) and/or 'O' (office use) |



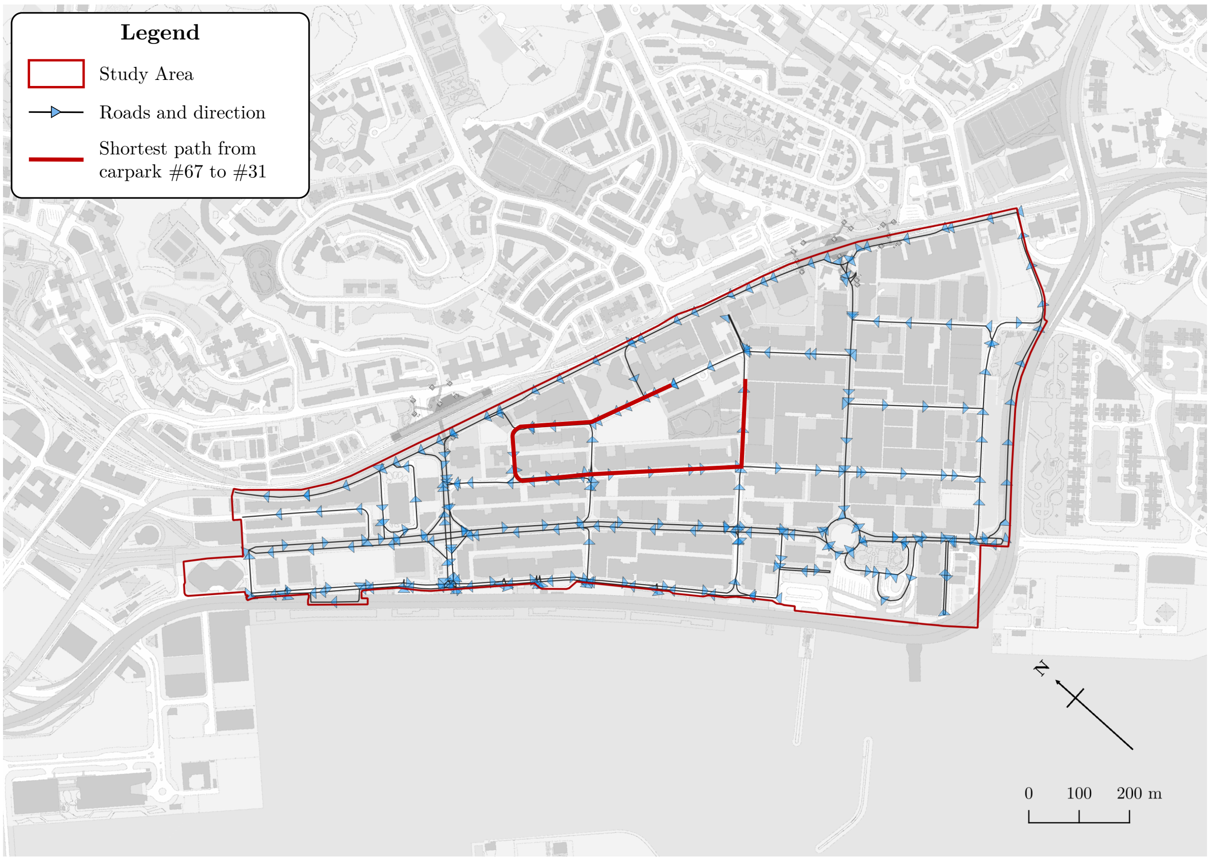

**Map 4**. Distribution of parking spaces and their amounts within the study area. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

In order to obtain the supply at every parking facility $j$, a digital "Road Network (2nd generation)" dataset is first downloaded through the HKMS2.0 portal ("Lands Department", 2021), and combining with GFAs of the corresponding building, the list of parking facilities is extracted using QGIS and listed in the Appendix.

### 5.1.4 Measurement of distance between locations

$$A_i = \sum\nolimits_j \frac{S_j f(d_{ij}, d_i)}{\sum_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

In order to obtain an accurate distance between two points, a weighted directed graph is generated from the road network data downloaded in Section 5.1.3. By using the Dijkstra's algorithm, the shortest distance between two nodes could be found:




**Map 5**. A demonstration of finding the shortest distance from carpark #67 to carpark #31 using the Dijkstra's algorithm. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

Using the Dijkstra's algorithm, two sets of origin-to-destination (OD) matrices of distances are generated using the QNEAT3[4] plugin of QGIS:

1. Between each survey location $i$ and parking facility $j$ ($d_{ij}$)
2. Between each parking facility $j$ and demand node $k$ ($d_{jk}$)

[4] An open-source QGIS plugin for network analysis, available at: https://github.com/root676/QNEAT3

### 5.1.5 Service catchment distance

$$A_i = \sum_j \frac{S_j f(d_{ij}, \color{red}{d_i})}{\sum_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

Since the service catchment distance ($d_i$) is the maximum driving distance of a vehicle, it can be calculated by the product of the average velocity (Transport Department, 2021) and the average search distance (Lau et al., 2005) of vehicles:

$$d_i = v_i t_i$$

$$d_i = \frac{21.6 \text{ km h}^{-1}}{3.6 \text{ km h}^{-1} \text{ s m}^{-1}} \times 2.7 \text{ min} \times 60 \text{ s min}^{-1} = 972 \text{ m} \tag{5.1.5.1}$$

### 5.1.6 Demand catchment distance

$$A_i = \sum_j \frac{S_j f(d_{ij}, d_i)}{\sum_k D_k f(d_{jk}, \color{red}{d_j})} \tag{5.1.1.4}$$

Similar to Section 5.1.5, since the demand catchment distance ($d_j$) is the maximum walking distance, it can be calculated by the product of the average velocity of pedestrians (Master Alliance Ltd., 2021) and the average search distance (Lau et al., 2005):

$$d_j = v_j t_j$$

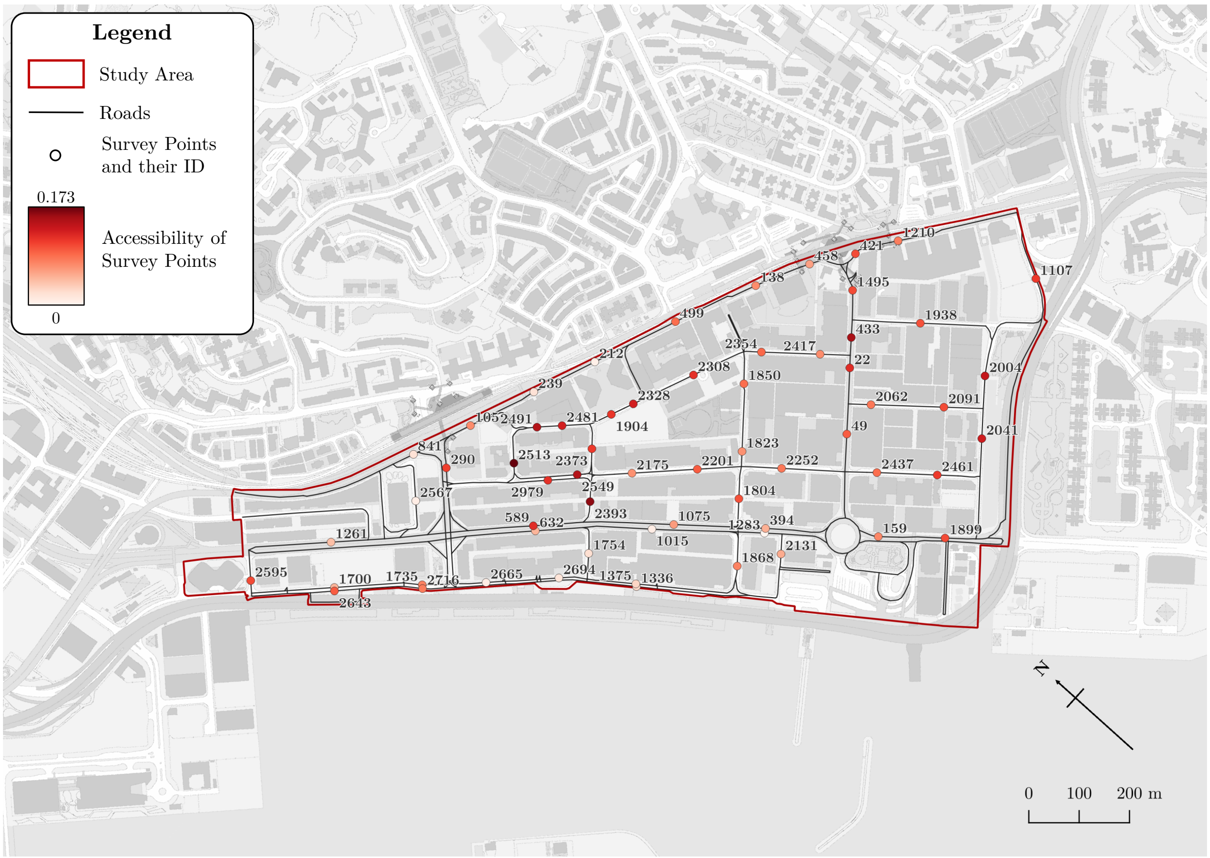
$$d_i = \frac{62.7 \text{ m min}^{-1}}{60 \text{ s min}^{-1}} \times 2.9 \text{ min} \times 60 \text{ s min}^{-1} = 181.83 \text{ m} \tag{5.1.6.1}$$

### 5.1.7 Sampling method

To maximise data representativeness and to reduce the time needed to collect samples, it has been decided to employ the stratified sampling technique, where each major road segment is sampled 1-2 times. In order to maximise data accuracy, the following constraints are set for survey points:

- should be as equally distributed as possible
- should not be located at/within close proximity to intersections/roundabouts, as vehicle speed is almost always lower than expected due to safety considerations

62 sample points across the study area have been selected, of which can be found in the Appendix and Map 5.




**Map 6**. The distribution of selected sample points and their accessibility index $A_i$. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

## 5.2 Traffic congestion

As explored in Section 2, the best measure for traffic congestion is speed. The relative traffic speed at a fixed survey location can be estimated by the formula (Kidando et al., 2017):

$$v \propto \frac{O}{q} \tag{5.2.1}$$

where:

| | |
|---|---|
| O | Time-occupancy, percentage time occupied by a vehicle (*dimensionless*) |
| $q$ | Flow of traffic (vehicles per hour) |

A custom web-based interface has been developed to collect both parameters.

### 5.2.1 Time-occupancy

Time-occupancy is defined as:

$$O = \frac{\sum_i t_i}{T} \tag{5.2.1.1}$$

which is the ratio between the sum of time measurements when the line-of-sight is occupied by the vehicle ($t_i$) and the total time ($T$).

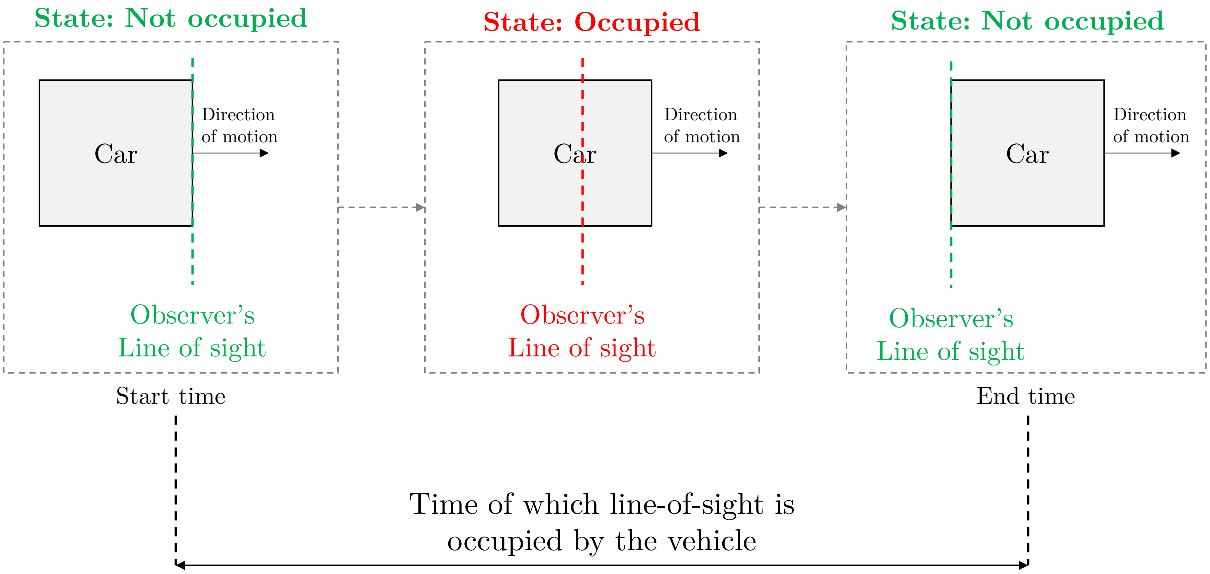



**Figure 6**. Visual representation of how time-occupancy is calculated.

The web interface is designed to operate on a touch-enabled smartphone[5], which will convert touch measurements into a single JSON data file[6] containing timestamps that describe the occupancy at that instant, with an instrumental uncertainty of 1ms:

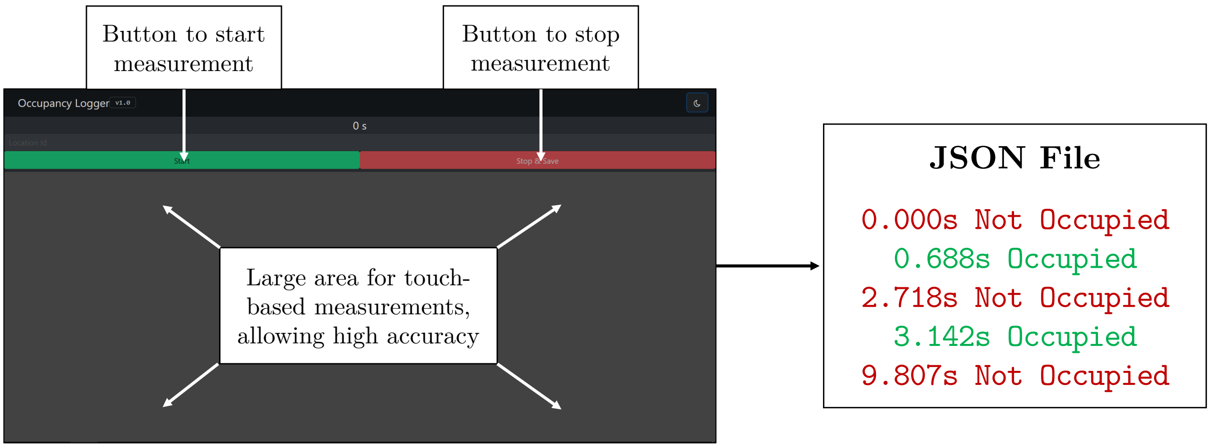



**Figure 7**. Interface of logging tool and its output.

### 5.2.2 Flow

Since flow is defined as:

$$q = \frac{N}{T} \tag{5.2.2.1}$$

The number of vehicles ($N$) passing through the time period can be directly derived by counting the number of "occupied" states in the JSON file of Section 5.2.1[7].

[5] The interface is mainly written in JS. Source code: https://github.com/cathaypacific8747/occupancy-logger.

[6] A commonly used standardised machine-readable text-based format for representing data.

[7] The Python code used to derive the time-occupancy and flow from the original JSON file can be found in the Appendix.

## 5.3 Precautions for surveying

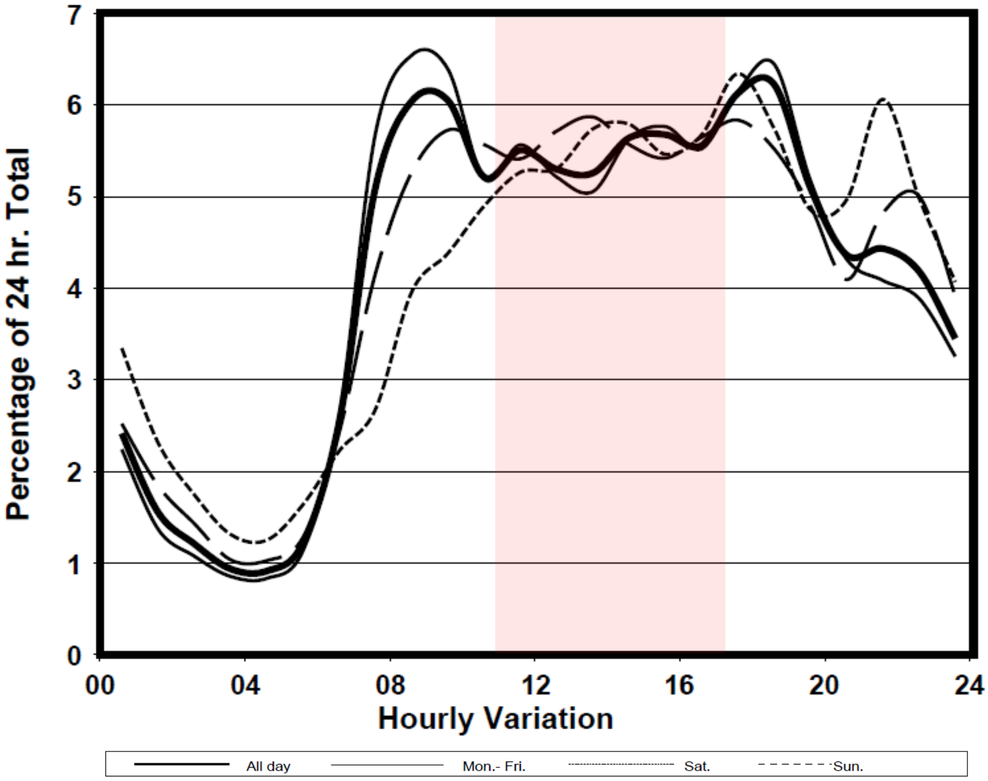



**Figure 8**. Graph of daily and weekly traffic changes at Station #3012 (Transport Department, 2021).

Regarding the optimum time of survey, in order to reduce data fluctuations, it has been decided to perform the surveying on weekdays between 10a.m. and 4p.m. because the traffic flow is rather stable and has a sufficiently large volume (see Figure 5), and the time interval where industrial activities are the most active (Labour Department, 2013). It has been decided to complete the entire surveying on one day to reduce the possibility of unpredictable events such as weather from affecting the rate of traffic generation.

## 5.4 Hypothesis Testing

### 5.4.1 Spearman Rank Correlation Coefficient (SRCC)

A SRCC test is used to determine the magnitude of two variables. When compared to Pearson's Product-moment Correlation Coefficient (PMCC), SRCC is insensitive to outliers and produces highly accurate measures of correlation especially for nonlinear relationships (Lovie, 1995). The SRCC is given by:

$$R = 1 - \frac{6\sum d^2}{n^3 - n} \tag{5.4.1.1}$$

where $d = r(x) - r(y)$, as detailed below:

Rank by increasing order

If ranks are equal, take the average

| **Accessibility**, $x$ | **Rank of** $\boldsymbol{x}$, $r(x)$ | **Relative speed**, $y$ | **Rank of** $\boldsymbol{y}$, $r(y)$ | **Difference**, $d$ | $d^2$ |
|---|---|---|---|---|---|
| 0.001698 | 0 | 5487 | 5 | -5 | 25 |
| 0.003340 | 1 | 4380 | ~~3,4~~ 3.5 | -2.5 | 6.25 |
| 0.008747 | 2 | 4380 | ~~3,4~~ 3.5 | -1.5 | 2.25 |
| 0.016384 | 3 | 1252 | 2 | 1 | 1 |
| 0.019683 | 4 | 343 | 1 | 3 | 9 |
| | | | | **Sum,** $\Sigma d^2$ | 43.5 |

**Figure 9**. A table for calculating $\sum d^2$ from the accessibility ($x$) and relative speed ($y$).

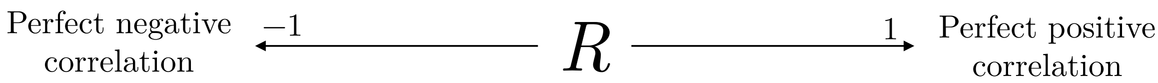



**Figure 10**. A general interpretation of the correlation based on the SRCC.

### 5.4.2 Student's T-test

To check whether the SPCC obtained above is statistically significant enough to reject the null hypothesis, the $t$-value must first be found:

$$t = R\sqrt{\frac{n-2}{1-R^2}} \tag{5.4.2.1}$$

The statistical significance can then be found by obtaining the one-tailed $p$-value using Excel:

$$p = \int_t^{\infty} f(u)\, du \tag{5.4.2.2}$$

where $f$ is the probability density function and $t$ the $t$-value. If the calculated $p$-value is less than the accepted $p$-value of $\alpha = 0.05$, the null hypothesis can be rejected.

# 6 Data Analysis

In order to better highlight the correlation between both variables and to aid with the identification of outliers, a scatter graph with a linear line of best fit has been used. In addition, a multivariate dot map is used to better visualise the geospatial patterns in traffic congestion and accessibility.

## 6.1 Macroscopic Trend

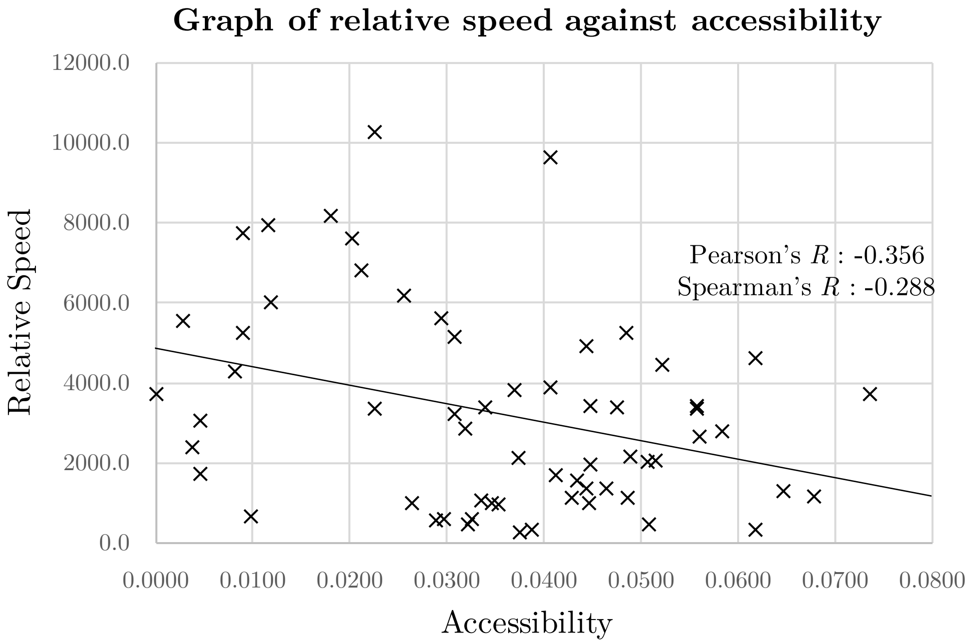



**Figure 11**. A scatter graph showing the relationship between relative speed against accessibility.

| Parameter Name | Symbol | Value |
|---|---|---|
| Number of data points | $n$ | 62 |
| Spearman's Rank Correlation Coefficient (SRCC) | $R$ | $-0.288$ |
| $t$-value | $t$ | 2.327 |
| $p$-value | $p$ | 0.0116 |
| Null hypothesis rejected? | Yes, as $p < 0.05$ | |

**Table 1**. Statistics regarding the Spearman's rank correlation testing.

As the SRCC is $-0.288$, there is a very weak negative correlation between vehicle speed in accessibility. As discussed in the methodology, since low vehicle speeds are a common characteristic of severe traffic congestion, and that the $p$-value is below the accepted value, the correlation is statistically significant enough to reject $H_0$.

However, it should be noted that while the $H_1$ has been accepted statistically, the poor reliability of the correlation cannot be used to definitively imply that parking accessibility is the *only* causation of traffic congestion (Coleman et al., 2015). The following sections will be focused on the qualitative justification of whether the two variables are truly correlated.

### 6.1.1 Heteroscedasticity

In regression analyses, it is assumed that dependent variables are homoscedastic, meaning that the variance is constant.

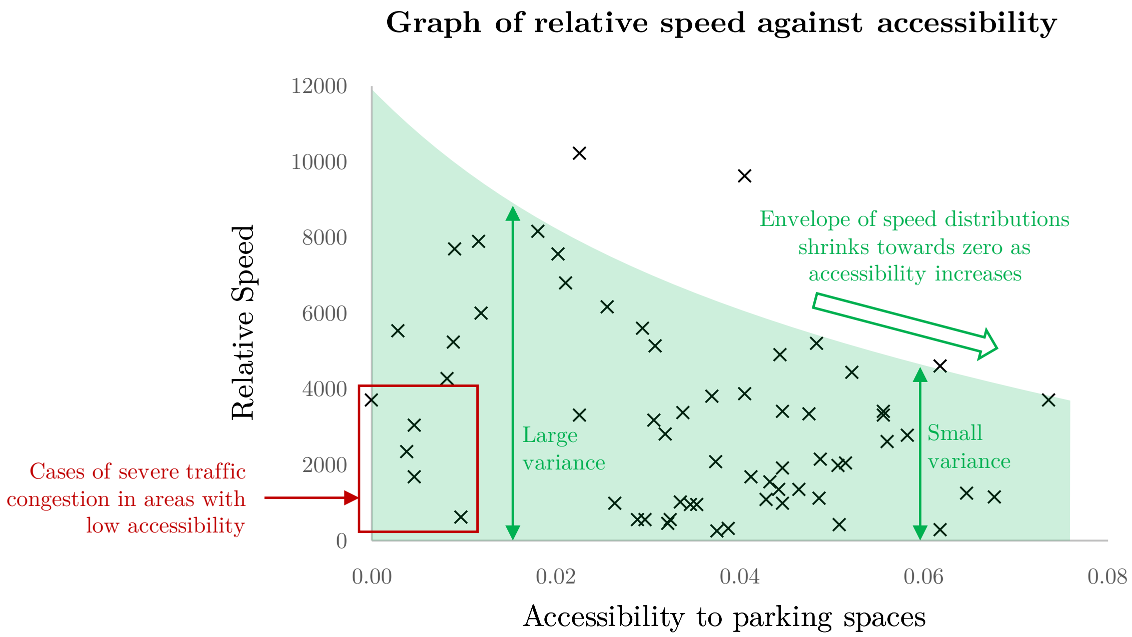
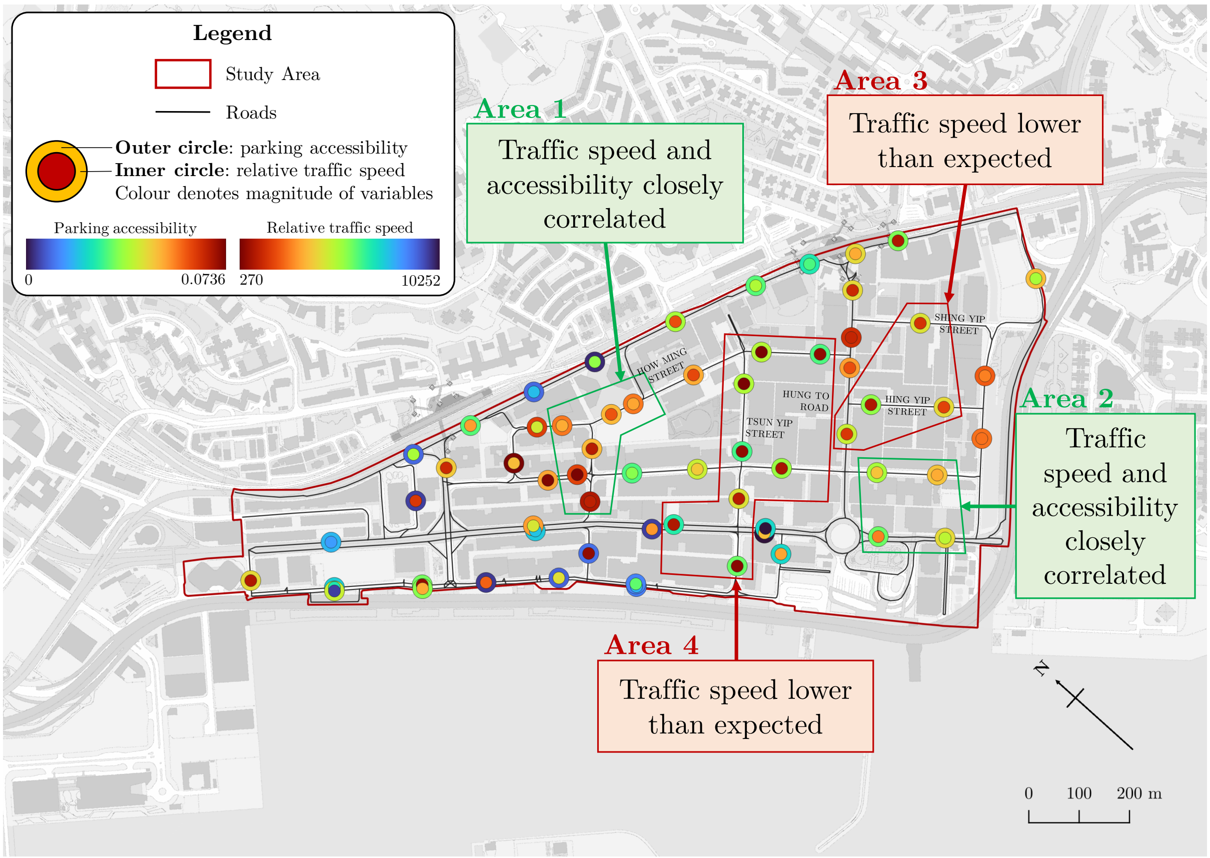



**Figure 12**. Demonstration of how heteroscedasticity can contradict with the acceptance of $H_1$.

However, the above shows that the variance of speed is unequal. As Goldberger (1964) suggests, heteroscedastic data can lead to Type I errors in hypotheses testing, where $H_0$ is falsely rejected when $H_0$ is in fact true.

When $H_1$ is accepted, it would mean that it is improbable to experience severe traffic congestion in areas with low parking accessibility. However, this statement is fundamentally flawed because this phenomenon occurred multiple times above. It would therefore be more accurate and representative to interpret the data by that: there may be a higher probability of experiencing less traffic congestion in areas with low parking accessibility.

## 6.2 Qualitative Analyses




**Map 7**. A multivariate dot map showing the accessibility and speed of survey locations. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

The multivariate dot map above shows the spatial distribution of survey locations and the extent of each variable. If the colour of the inner circle is roughly equal to the outer circle, both variables are closely correlated; whereas if the colours are starkly different, it can suggest a mismatch in the predicted speed.

As an example, severe traffic congestion in Area 1 has been correctly predicted, as it is within close proximity to abundant parking spaces in carparks #65 and #66. Some areas with less severe traffic congestion have also been correctly predicted, especially in Area 2 where parking availability is limited along an arterial road that travels out of KT.

However, there are some notable large-sized areas where the severity of traffic congestion is often underestimated, which is seen to propagate down the entire road. This happens in Area 3, which seems as if a traffic queue has developed and extended along Tsun Yip Street, as well as Area 4, which also seems to exhibit the same effect in the loops formed by Hing Yip Street and Shing Yip Street. This phenomenon appears to echo with the argument made in Section 6.1.1, where areas of low parking accessibility appear experience unusually severe traffic congestion. Therefore, given that there are strong macroscopic anomalies and spatially distinct regions where traffic flow seems to be obstructed by external factors, the following sections will aim to uncover potential reasons for this phenomenon.

### 6.2.1 Physical barricades blocking access to on-site


**Figure 13**. Demonstration of how physical barricades indirectly obstruct traffic flow and worsen traffic congestion. (841058, 819220$^{\text{EPSG:2326}}$)

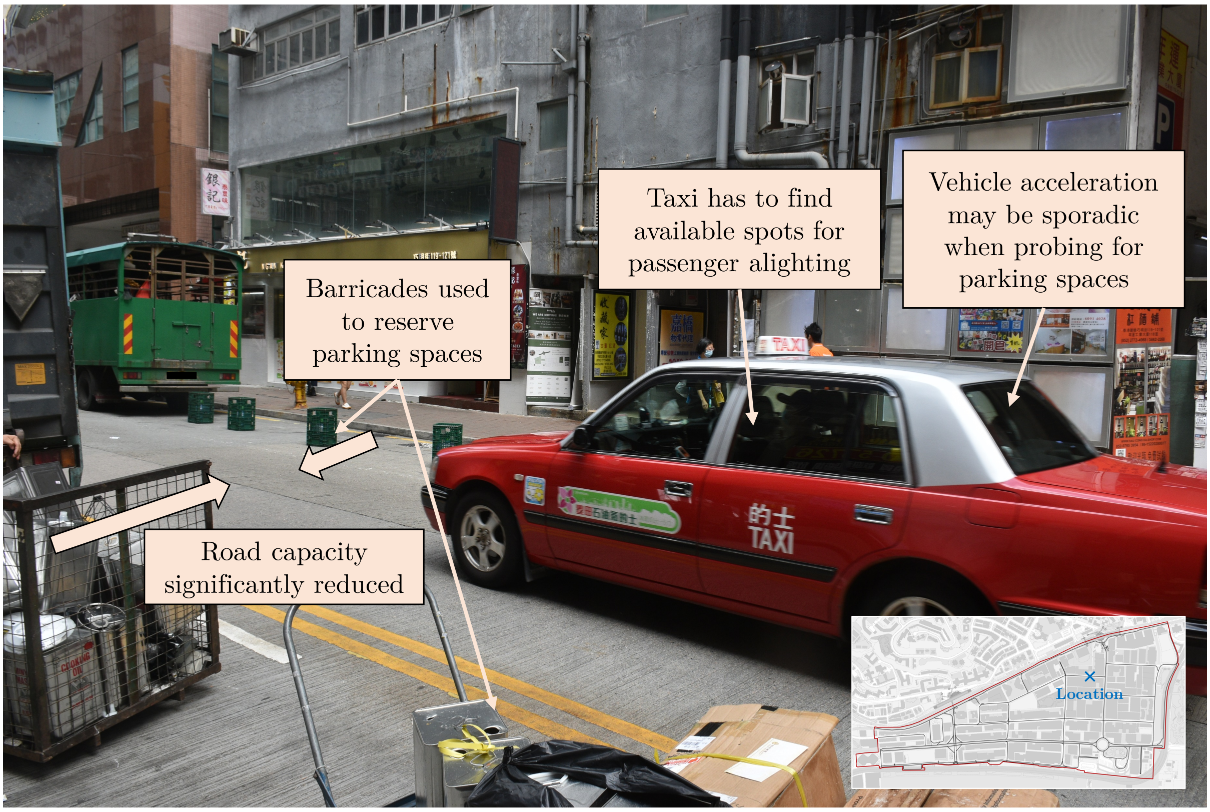



**Figure 14**. Demonstration of how barriers can impede taxis from alighting passengers. (841029,819196$^{\text{EPSG:2326}}$)

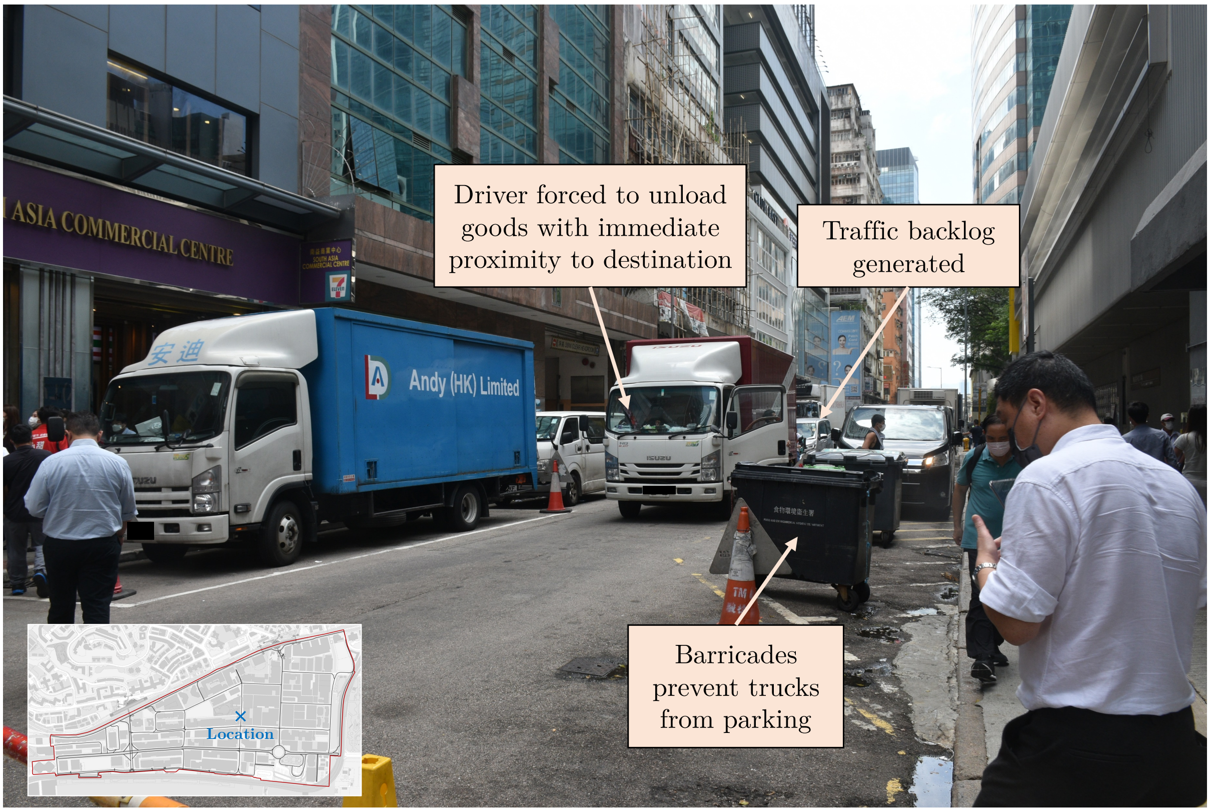



**Figure 15**. Another instance of a truck being forced to unload goods due to barricades blocking access to on-street parking spaces. (841036,819202$^{\mathrm{EPSG:2326}}$)

In the three instances above, it has been observed that various objects have been placed at on-street parking spaces. This disables the opportunity for incoming vehicles to park at the supposed free space, and hence unable to unload goods or alight passengers. Thinking from the driver's perspective, knowing that the barricades placed are unlikely to be removed, and considering that cruising around the area until the parking space is free will incur too much extra cost and time, the driver is therefore forced to make the decision of unloading goods at the immediate proximity to their destination. However, the stoppage of the vehicle at the only lane available essentially brings the traffic behind to a complete standstill. Not only does this have the immediate effect of bringing the vehicle velocities to zero, but sudden traffic halts also often propagate in a "wave-like" manner downstream and across street grids (Li et al., 2019), as observed along the length of Tsun Yip Street. Furthermore, given the fact that barricades reduce the effective number of usable lanes, this causes the road capacity to be easily oversaturated, hence justifying how traffic congestion is not independent from parking accessibility, rather heavily influenced by barricades.

Upon closer inspection, it can be seen that such barricades (rubbish bins, trolleys, and light cartons) are highly mobile. The particular choice of using easily and quickly movable objects suggests that they are used for pre-reservation purposes by select users. Although the law specifically prohibits obstructing parking spaces (*"Cap 374C"*, 2021), for one to willingly violate regulations just to secure a parking spot, reflects that perhaps parking availability in the entire region is extremely scarce and competitive.

### 6.2.2 Illegal parking and double parking

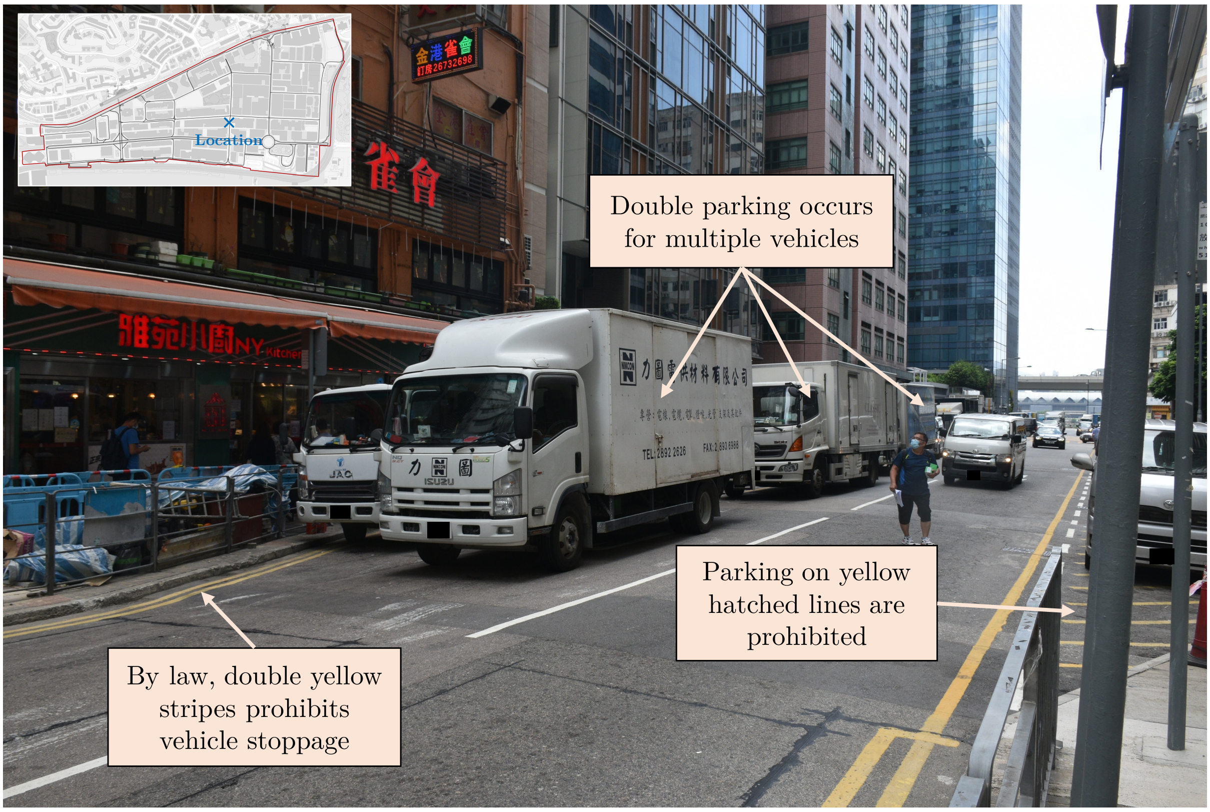



**Figure 16**. Photo of illegal parking and double parking. (840899,819090$^{\text{EPSG:2326}}$)

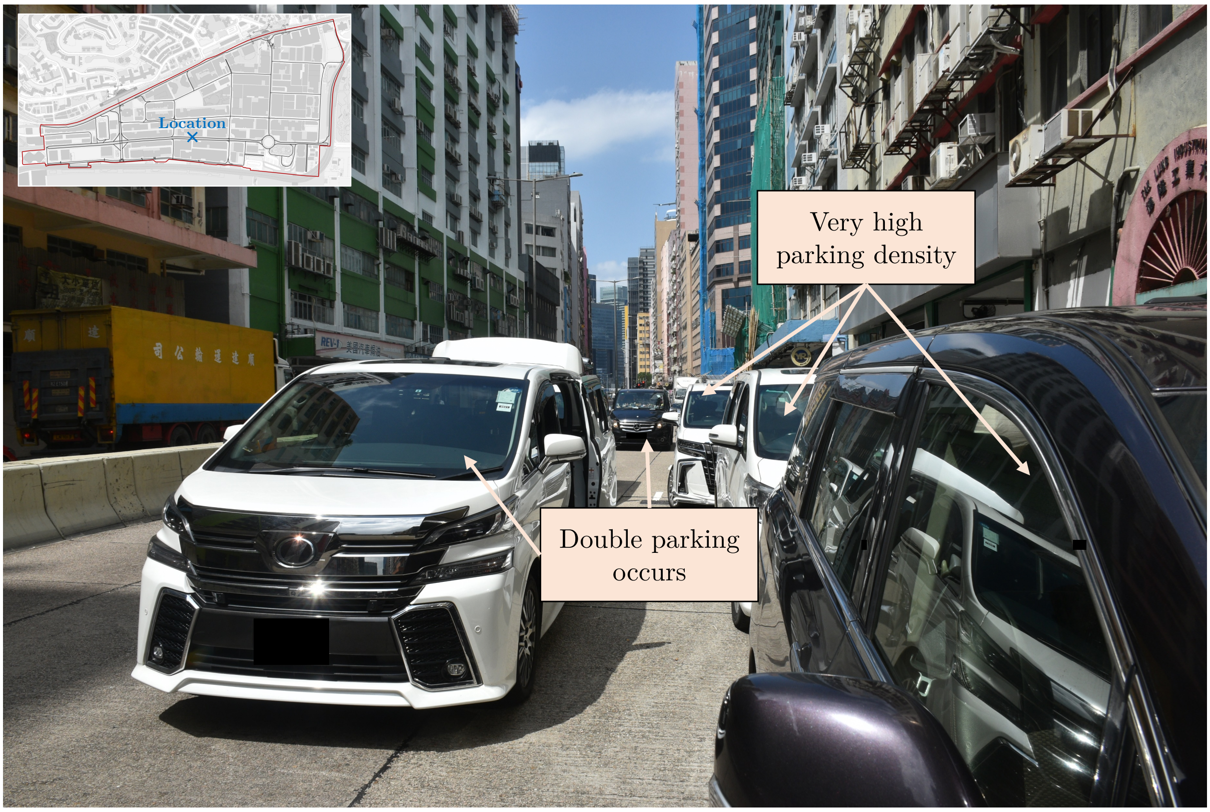



**Figure 17**. Photo of double parking. (840727,819155$^{\text{EPSG:2326}}$)

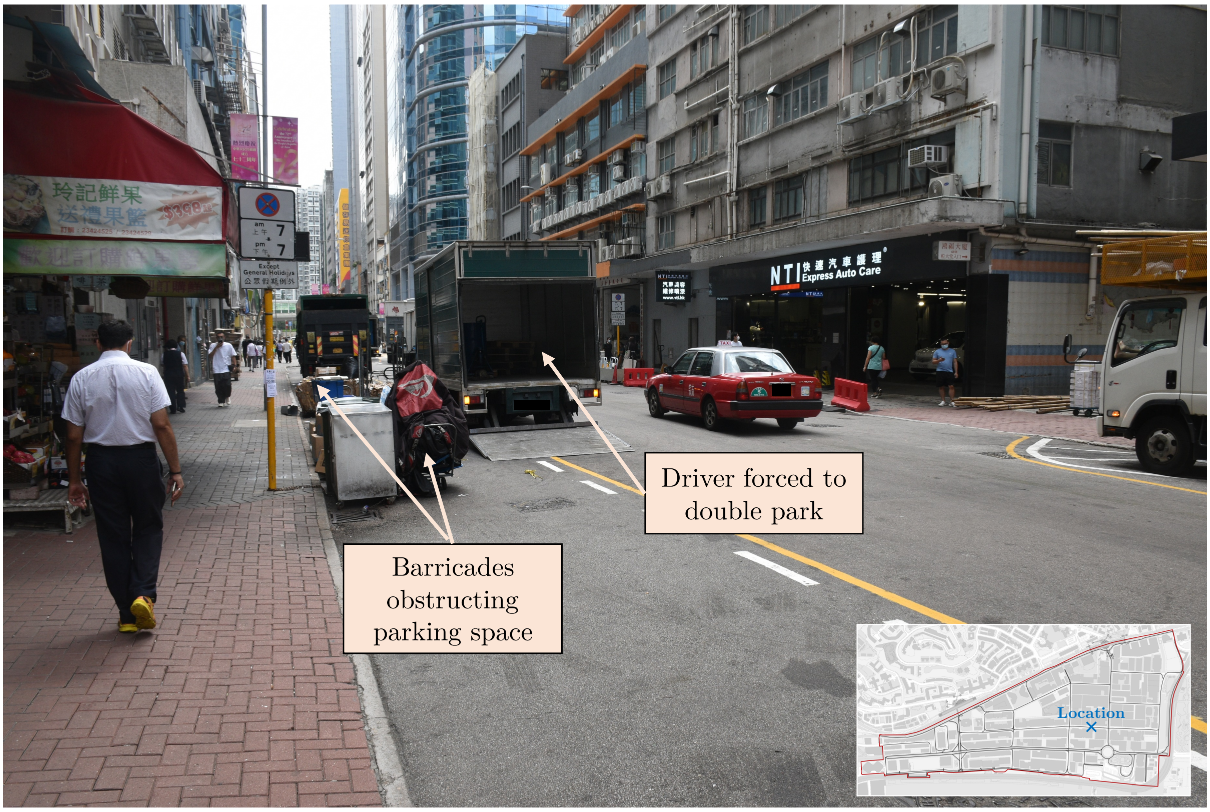



**Figure 18**. Photo of barricades causing double parking. (840996,819203$^{\mathrm{EPSG:2326}}$)

By HK law (*"Cap 374C"*, 2021), vehicles are disallowed to park on roads with double yellow stripes, yellow hatched lines, boxed yellow road markings, or park beside vehicles that have already occupied the parking space (known as "double parking" ref). Yet, illegal parking is observed to appear throughout the region.

Illegal parking can occur due to many factors, the most dominant being the insufficiency of parking spaces (ref). This is reflected in Fig.17, where the parking density is very high, causing drivers to resort to double parking. Double parking is a type of bottleneck, where vehicles are suddenly required to merge several lanes into one. Since this process takes coordination, vehicular velocity is again reduced significantly, and combined with the amplifying characteristic of traffic congestion as discussed in Section 6.2.1, the effect of double parking on traffic congestion is significant.

From Figs 16 and 17, it has been observed that once the first vehicle takes the initiative to double park, it can be analogised by the deposition of a boulder in a river, which then reduces the water velocity behind it, encouraging the agglomeration other sediments. It can therefore be said that the infectious nature of double parking can potentially pose a greater effect on traffic congestion than parking accessibility.

### 6.2.3 Pedestrian interruption of traffic flow

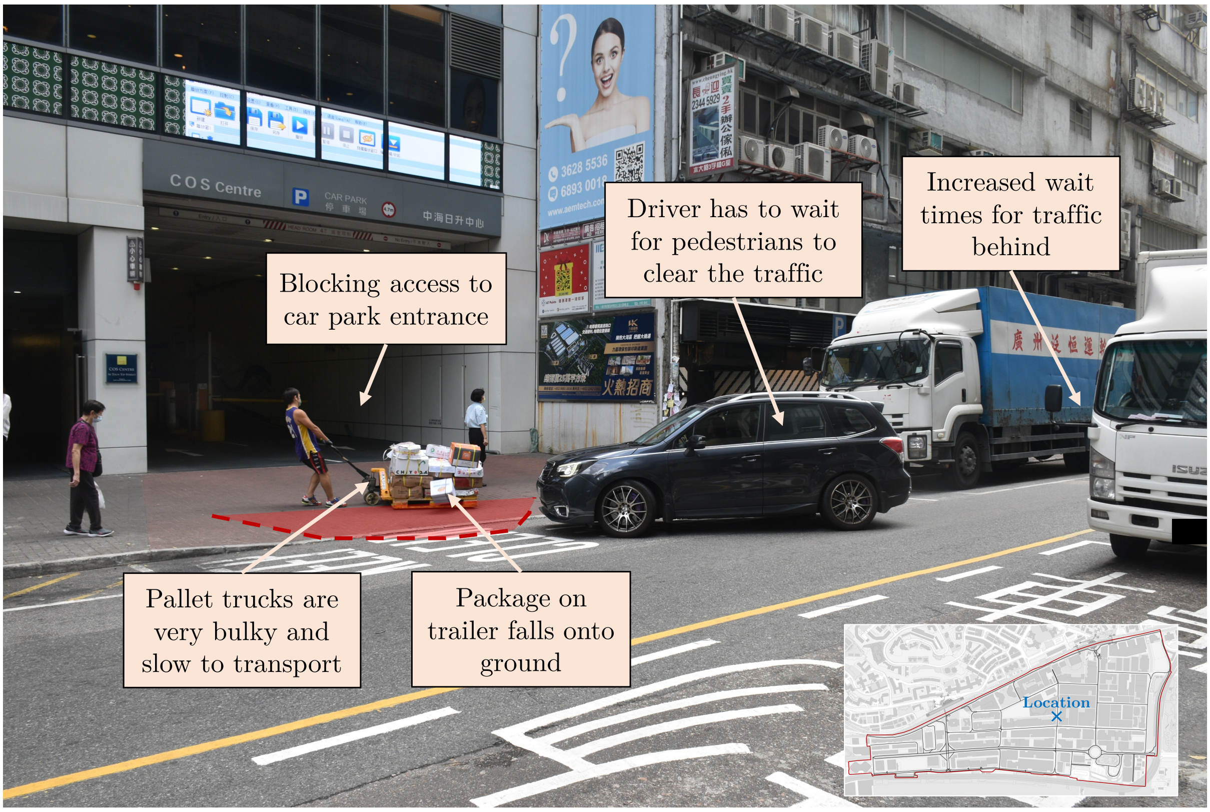



**Figure 19**. Photo of delivery workers blocking the entrance to a car park. (840967,819144$^{\text{EPSG:2326}}$)

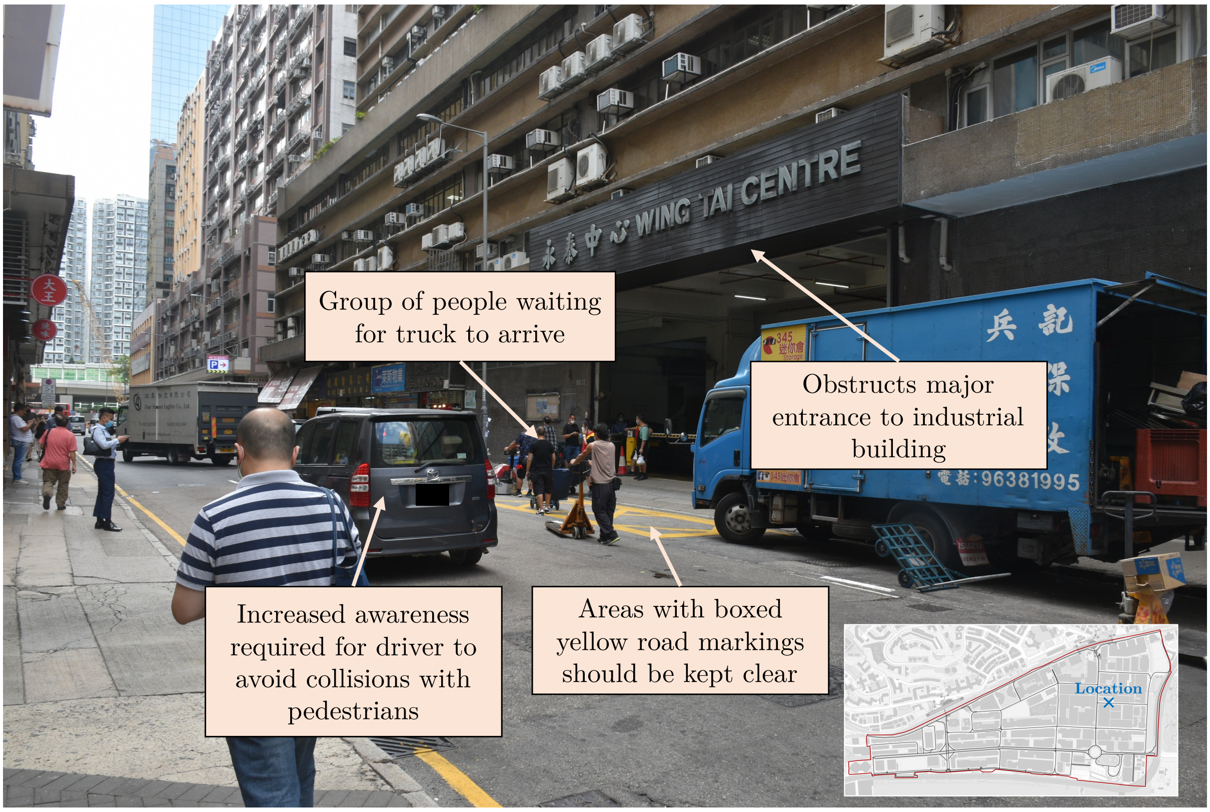



**Figure 20**. Photo of a group of delivery workers congregating, indirectly reducing traffic speed. (841204,818978$^{\text{EPSG:2326}}$)

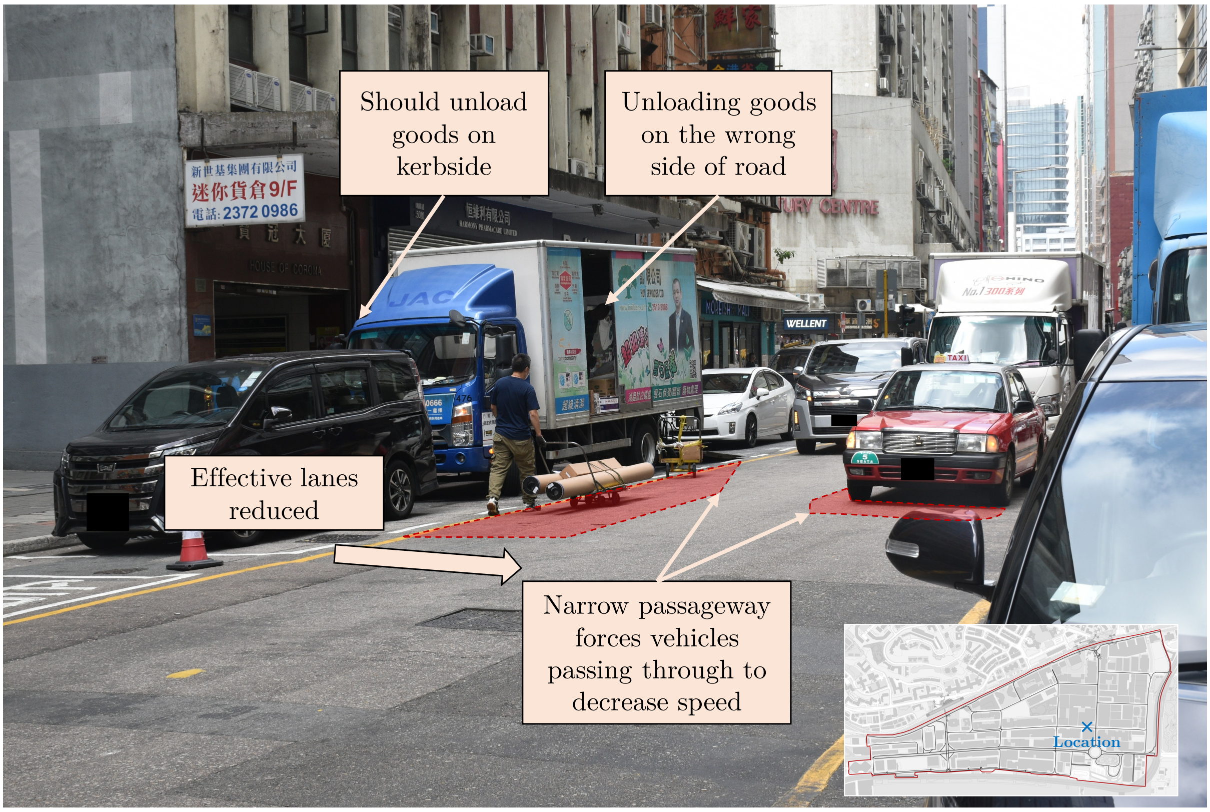



**Figure 21**. Demonstration of how unloading goods on the wrong side of the road can create bottlenecks in traffic. (841023,818988$^{\text{EPSG:2326}}$)

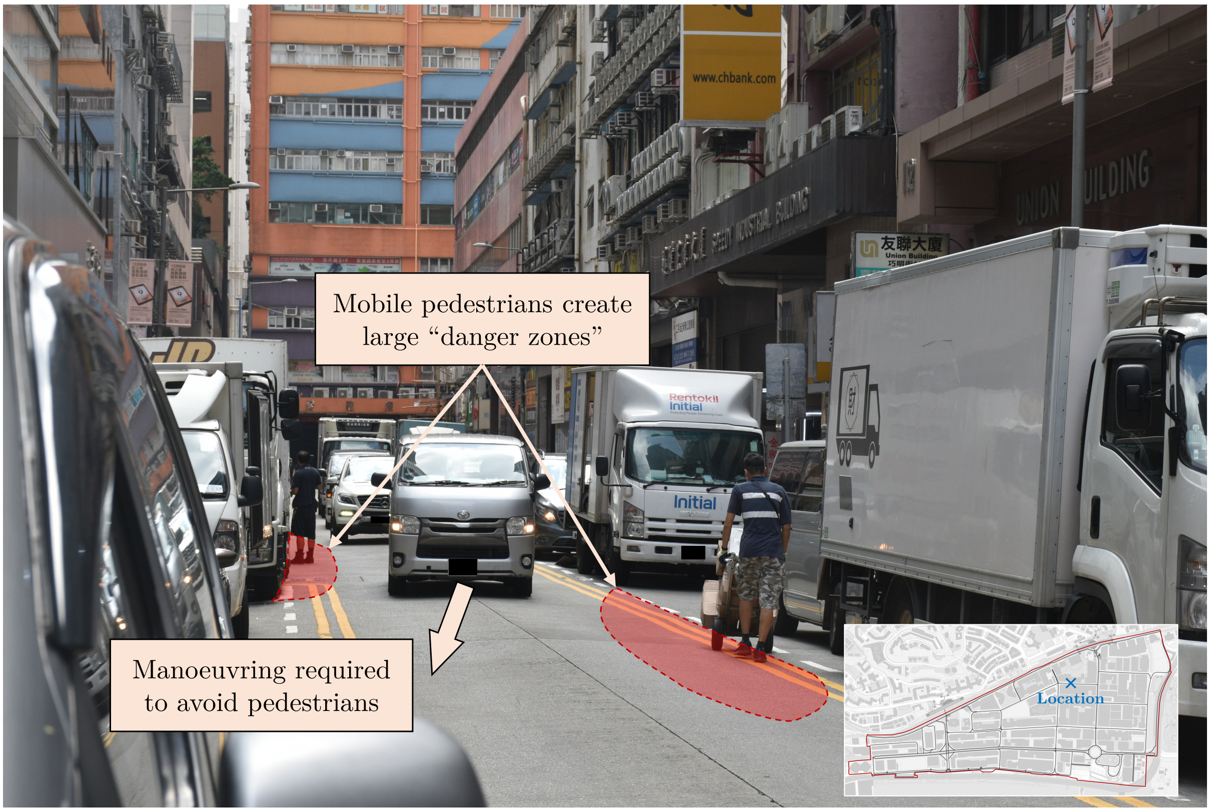



**Figure 22**. Demonstration of how mobile pedestrians cause drivers to slow down. (841140,819200$^{\text{EPSG:2326}}$)

The walkability of KT has been categorised as level E, the worst level (Master Alliance Ltd., 2021). Similar to vehicular congestion, poor walkability is characterised by low speeds and high densities. Since KT is an industrial district where deliveries are frequent, it is unsuitable for bulky trailers, trollies, or pallet trucks to operate efficiently and safely on the kerb. Deliveries are therefore often transported on the more spacious road, but also creates the barricading effect as discussed previously.

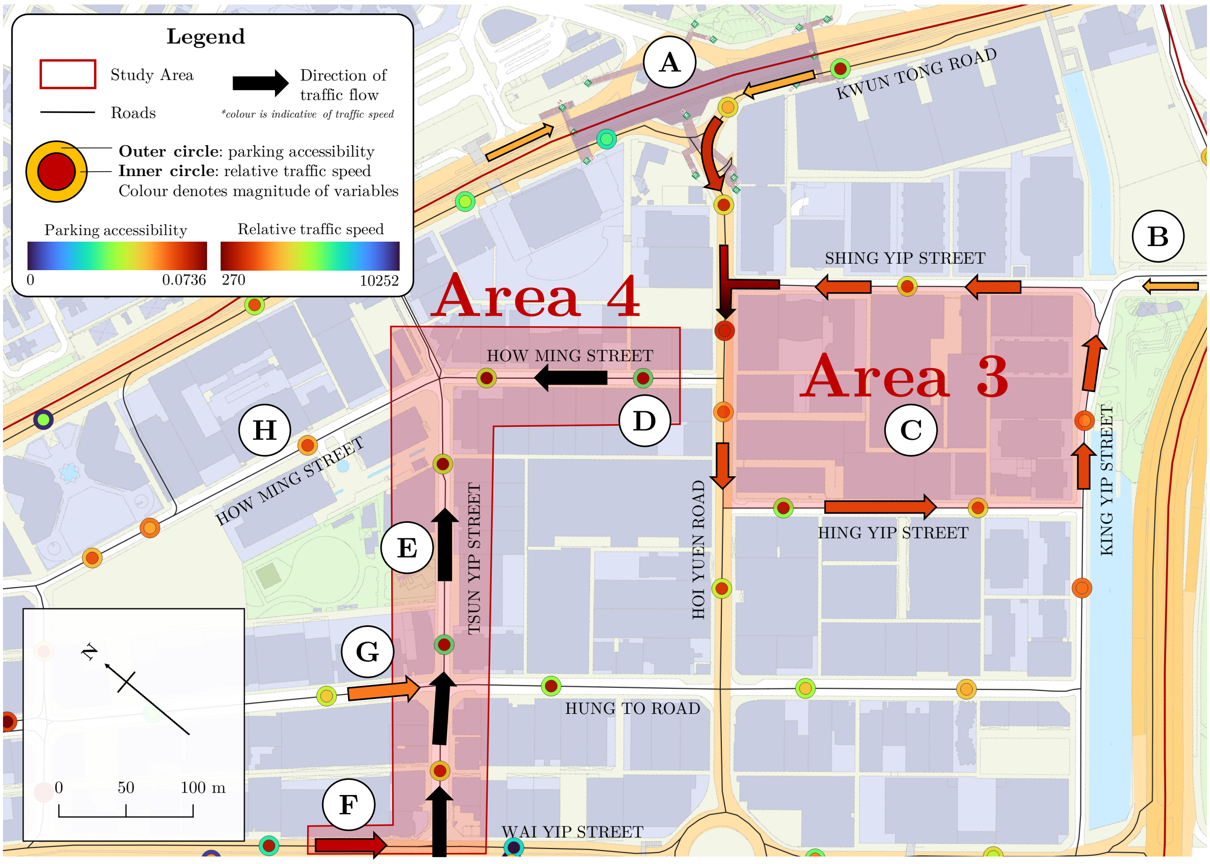
In addition, it has been scientifically proven that drivers exhibit a more sensitive physiological response to humans than objects. As a result, when drivers are subject to humans, vehicular speed are often reduced, and acceleration may be more sporadic to account for the uncertainty in human movements. Trailing vehicles are also observed to have an increased separation distance, hence overall inducing traffic congestion. It has one again been demonstrating that parking availability is only one of the minor factors for congestion.

### 6.2.4 Inefficient road design

Lastly, it can be said that the aforementioned sources of congestion are mostly originated from human-based interactions with their surroundings, for example:

- **6.2.1 Physical barricades blocking access to parking spaces**
  Preoccupation of parking space forces vehicles to unload goods immediately, blocking traffic behind
- **6.2.2 Illegal and double parking**
  Industrial operations are time-critical, immediate access to building required, generating a bottleneck when double parking occurs
- **6.2.3 Pedestrian interruption of traffic flow**
  Delivery workers transporting goods on main road, causing sporadic accelerations

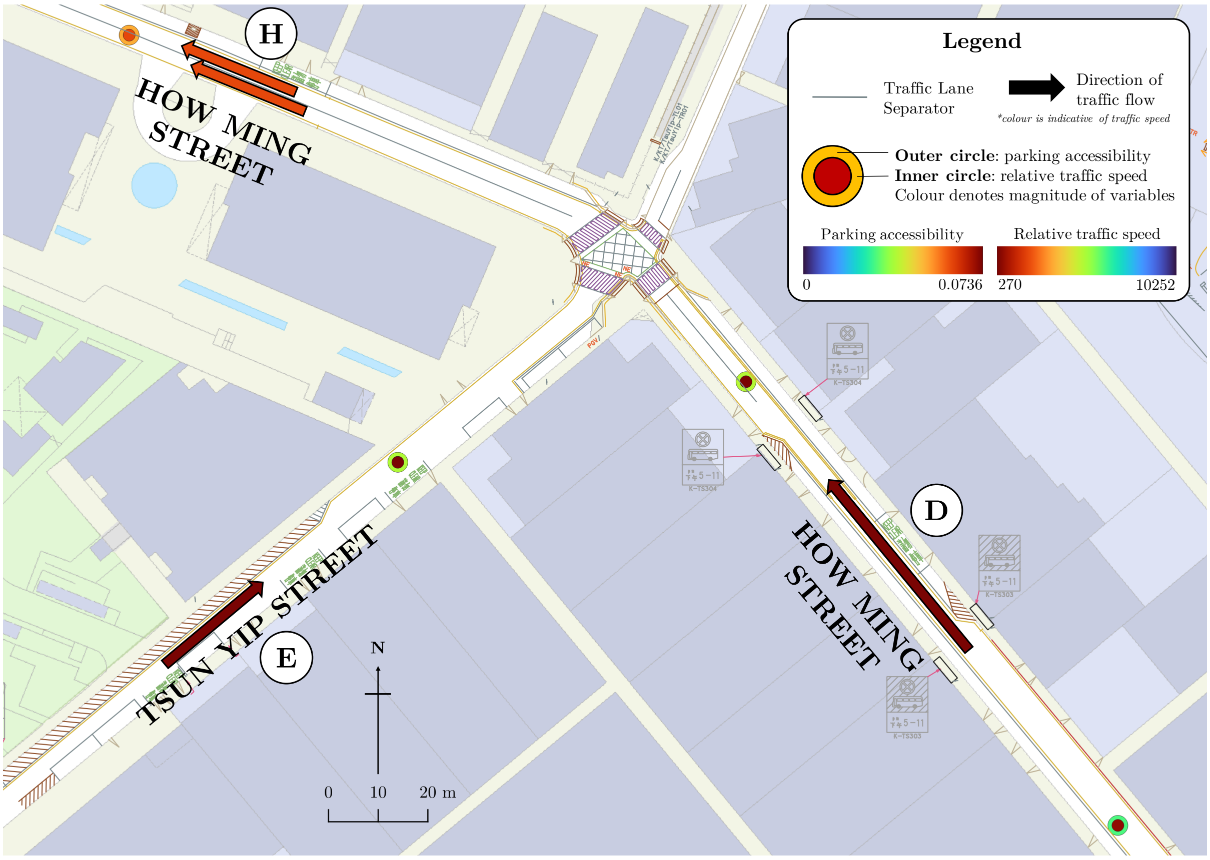
However, most of these situations arise from some sort of physical limitation of the road, such as insufficient lanes. Since correct road designs are critical to maintaining a high throughput of traffic, it is important to check whether lanes are correctly positioned and routed so to avoid unwanted congestion. Therefore, this section will attempt to incorporate observations during the field study with data to derive an explanation for the existence of over-congested regions.




**Map 8**. Map of two most visually distinct over-congested regions. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

In Area 3, it has been observed that Shing Yip St., Hoi Yuen Rd., Hing Yip St. and King Yip St. forms a closed anti-clockwise loop Ⓒ, giving the opportunity for drivers to linger and encircle the area infinitely. From a 5-minute observation made at Shing Yip St., there were 3 private car drivers that have stopped temporarily on the kerbside before shortly departing. This supports that the circular road formation may have worsened the congestion.

In Area 4, it is also obvious that How Ming St. (Ⓓ) receives a large amount of traffic from Ⓐ and Ⓑ, and Tsun Yip St. (Ⓔ) receives a large amount of traffic from Ⓕ and Ⓖ. In order to understand why Ⓓ and Ⓔ seem to be oversaturated, a zoomed-in view of the location is prepared below.




**Map 9**. Map of the intersection between Tsun Yip Street and How Ming Street. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

From above, after accounting for the lanes that are occupied by parking spaces, both Ⓓ and Ⓔ has one effective lane. The current traffic light implementation is of the following:

| Sequence | Number of effective lanes used Ⓔ | Ⓓ | Ⓗ | Number of underutilised lanes | Duration |
|---|---|---|---|---|---|
| 0 (Ⓔ green) | 1 | 0 | 2 | **1** | 01:20 |
| 1 (Ⓓ green) | 0 | 1 | 2 | **1** | 00:40 |
| 2 (Pedestrians) | 0 | 0 | 0 | 2 | 00:30 |

**Table 2**. Table of traffic light signals at junction between Tsun Yip St. and How Ming St.

In the above, when Sequence = 0, only 1 lane of Ⓔ is opened to 2 lanes of Ⓗ. This means that 1 lane of Ⓗ is theoretically never used, hence decreasing the potential volume by up to 50%, reflecting why the congestion might be so severe in Ⓓ and Ⓔ.

Therefore, with the combination of the loop formed in Area 3 and a potential misconfiguration of traffic lights at Area 4, inefficient road designs can worsen congestion.

*Needs more illustrations!*

# 7 Evaluation

Although the null hypothesis has been rejected, during the geographical enquiry process, specifically the analysis section, many errors and assumptions are actually found to be false, which makes the claim questionable.

## 7.1 Methodology

- In previous literature, although gravity models have gained a lot of support among geographers, it has just been theorised very recently in the 2000s, which may be unreliable
- 2SFCA has been historically mainly used to assess healthcare accessibility on a nation-wide scale, but never on traffic dynamics and such a microscopic level (<2km), hence unreliable and unproven
- (variable catchment distance 2SFCA) V2SFCA should also be used because commercial/business centres have a much larger catchment distance
- (multi-mode 2SFCA) MM2SFCA should also be used because trucks (especially rubbish trucks) have a considerably much less catchment distance (<50m) while cars can have a larger catchment distance
- Possible incorporate land use zoning + combine traffic generation/degeneration rates from TPDM 2019!

### 7.1.1 Region-wide insufficiency of parking spaces

- The hypothesis states that traffic congestion occurs when there is an excess of supply of parking spaces, but in fact from the survey 93.3% of respondents believe there is insufficient demand, which is contradictory → hypothesis should be re-evaluated
- "congestion is more likely to happen when cruising for parking happens" – in fact from observation there were almost no trucks cruising for parking, they just park whenever they could
- rather, industrial vehicles are less likely to cruise because they

### 7.1.2 Unsuitability of selecting service catchment distance ($d_{ij}$)

Intuitively the search distance of industrial vehicles are likely to be significantly less than expected (5 minutes) because the need for delivery efficiency is very high, do not have the capacity to delay the customer/time-critical jobs. Heavy deliveries cannot be carried very far because KT has a poor walkability/level of service + the rugged old-style streets significantly increase the friction of distance. Coupled by the old road layout, encourages double parking and significantly decreasing road capacity.

Behaviourally, drivers often perform a risk assessment as to determine whether they are willing to neglect traffic restrictions to trade for convivence. If the probability of receiving a traffic fine is lower than the opportunity cost of encircling the area, the driver is more than likely to park at any location they desire, hence leading to illegal and/or double parking. Furthermore, the fact that the study area is an industrial district only offers an even greater incentive for the driver park illegally, for the reasons below:

1. Goods are often **very bulky and heavy** to deliver for long distances, especially in such a heavily congested pedestrian zone (cite walkability/LOS) (see Fig.15)
2. If the driver decides to spend additional time to encircle the area for parking spots, the expenses arisen from missing or delaying time-critical deliveries can be devastating.

Comparatively to drivers for the purpose of shopping or entertainment, drivers are willing to walk the additional distance to avoid a parking fine. → evaluation of whether selecting the catchment distance of 972m is *actually* suitable, as it is far from reality.

Population catchment distance should be reasonable

#### 7.1.3 Assumption of equal parking fees across all car parks

- Did not take in account of more expensive car parks, for example, Millenium City is considerably higher (~$60/hr?), in fact according to survey 54.3% still think prices are too high, hence causing them to double park

#### 7.1.4 Selection of distance decay function

- "Consumers are likely to patronize a facility in their immediate proximity in lieu of equalizing the visit possibility within an arbitrary distance", so the flat peak is not really realistic
- Inverse distance (POW20, $d^{-1.5}$) is thought to be superior to the Guassian functions according to 10.1080/13658816.2019.1591415, should've used that

#### 7.1.5 Measurement of Traffic congestion

- Lane-switching causes measurements to be really awkward and sometimes vehicles can suddenly stop at the lane you're measuring and results go off → improvement = measure traffic data for all lanes if possible
- Lane selection is inconsistent – flawed representation. Since HK is left hand drive city, drivers unload people and goods on the leftmost lane, causing interruptions of traffic flow on the left, uneven distribution especially at Kwun Tong Rd. → improvement = measure traffic data for all lanes if possible
- Traffic lights can run for 2 minutes and if timed incorrectly can lead to large result differences
- Can be more accurate by incorporating vehicle detection, so vehicle length is known and hence more accurate speed measurements

### 7.2 Study Area

- Perhaps the choice of KT is unsuitable – given the fact that industrial vehicles and industrial-purposed vehicles are highly likely to patronise a facility in the immediate proximity, the large catchment distances are not reflected in real-world conditions, hence rendering the methodology inaccurate.
- Study area should be more commercially/retail oriented, where drivers *actually* have the incentive to park far from their destination, for example, Mong Kok, because they can't afford to keep the car illegally parked
- On-street parking spaces & private carparks not included (only 28.2% are open to the public[8])
- Should not have chosen KT because of its *renowned* traffic congestion, difference is probably going to be insignificant, so it's best to go to an area where there are actual differences to start with
- Macroscopically the parking space availability is severely lacking (90% of respondents say so), not whether there is a spatial imbalance of parking space. 54.9% believes parking prices are expensive, say they are willing to park for HKD11-20/hr

## 8 Conclusion

*To be completed*

[8] https://www.td.gov.hk/en/transport_in_hong_kong/parking/carparks/index.html

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# 10 Appendix

*Took me around 1 full day to format the code just ot have it all gone* ☹

*TBA: code*

*TBA: all buildings, survey points, spearman rank*

*TBA: photos of every single survey point*