An investigation into the traffic congestion in Kwun Tong, Hong Kong.

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

Personal code:[redacted]
Word Count: 3964

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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 number 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 hubs (“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 (QoL) 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

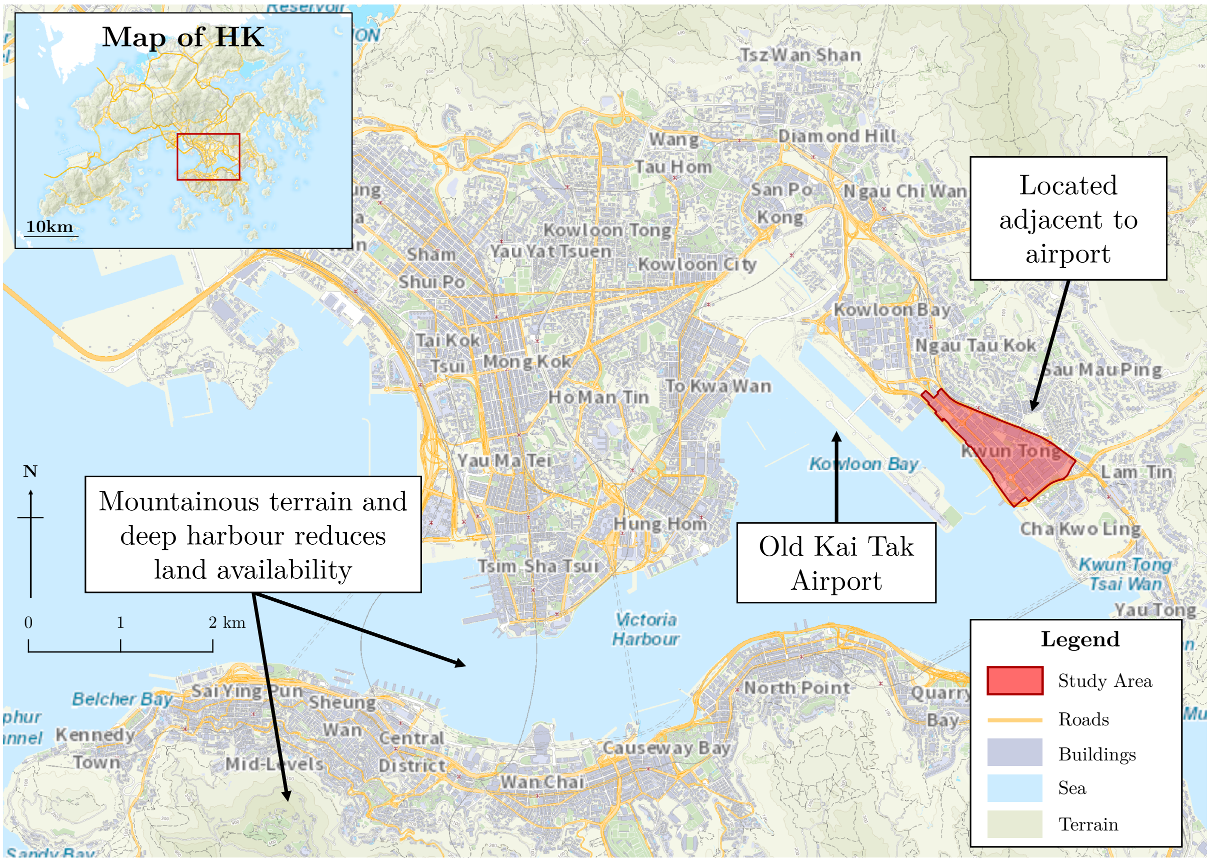
According to the Traffic Advisory Committee (2014), traffic congestion is one of the most important urban issues in HK. Many researchers have compared traffic congestion to fluid dynamics, outlining the three fundamental components, including flow, the number of vehicles passing through a point per unit 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 by 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), 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 to 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 kerbside 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 of 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 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 distances (Pinder and Witherick, 1972). Although the index provides an excellent general outlook on the inequity of services, the assumption 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 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 interest in applications such as the measurement of accessibility in healthcare services (McGrail, 2012; Chen and Jia, 2019).

3 Geographical Context



Located adjacent to airport

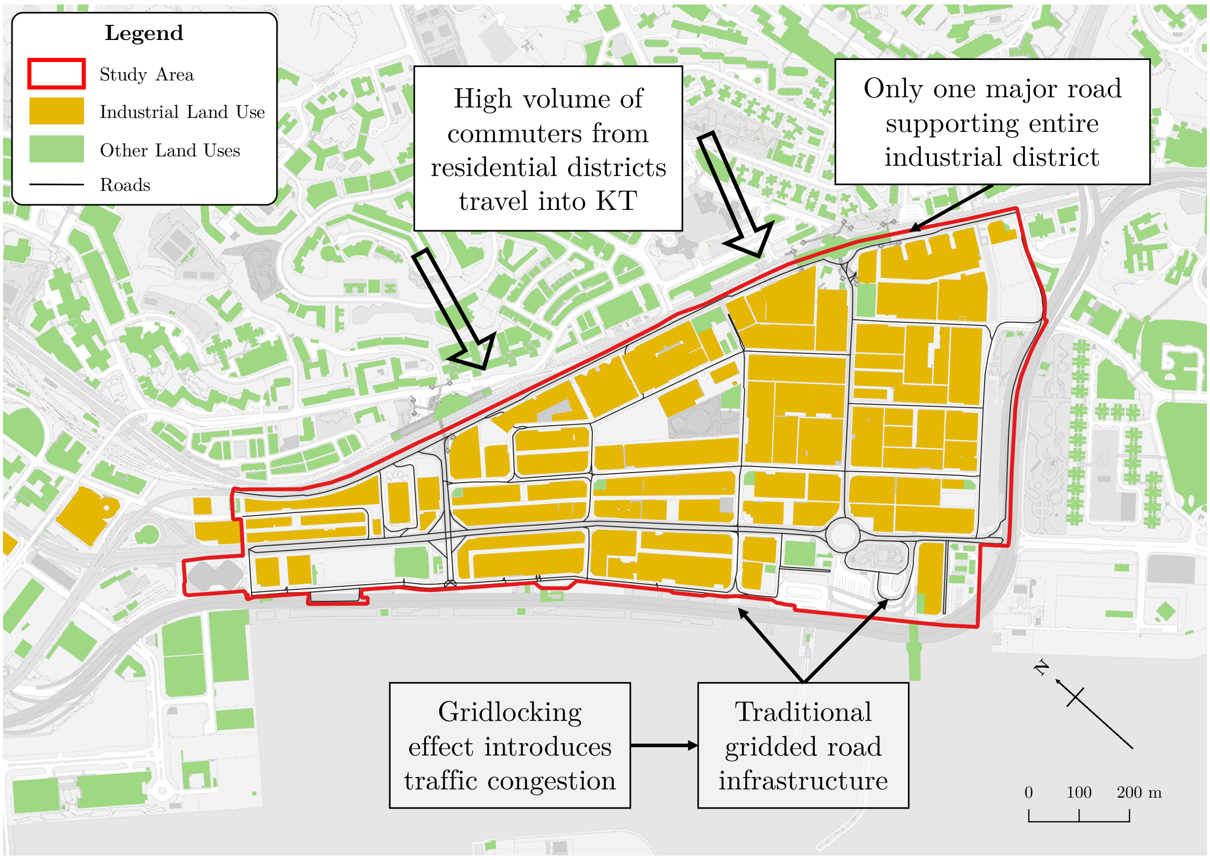
Mountainous terrain and deep harbour reduces land availability

Old Kai Tak Airport

Map 3.1. 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, land developers often construct tall buildings 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, 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 3.2. The road infrastructure and land use of the study area. (Hong Kong Geodata Store, 2021)

To boost economic productivity, KT has been designated as a satellite city (Scott, 1982), where industrial zones and residential areas are segregated from each other. Although distinct functional zones can increase the QoL in residential neighbourhoods and allow industrial activities to be centralised, high volumes of cross-commuting can 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

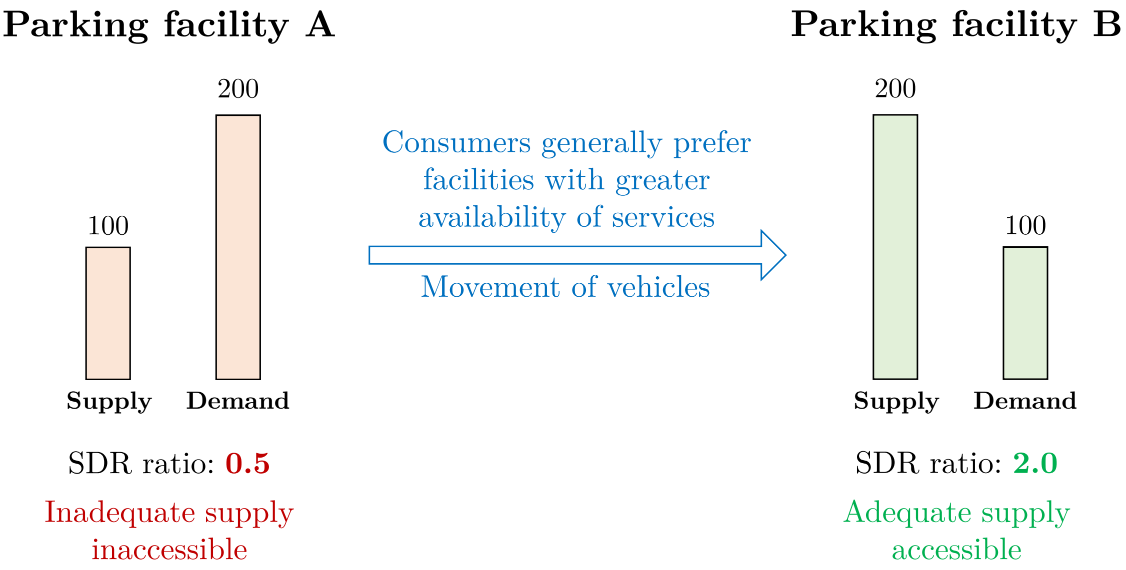


Figure 4.1. Demonstration of the movement of vehicles to areas with greater parking accessibility.

Where there is an imbalance in SDR, drivers tend to relocate towards areas with greater supply in parking spaces. While it is commonly believed that areas with adequate supplies of parking spaces can alleviate traffic congestion, the excess of supply can encourage drivers to *cruise* around the area in search of better parking prices (Millard-Ball et al., 2020). In areas where parking supply is limited, drivers often circle the area in *search* for available spots:

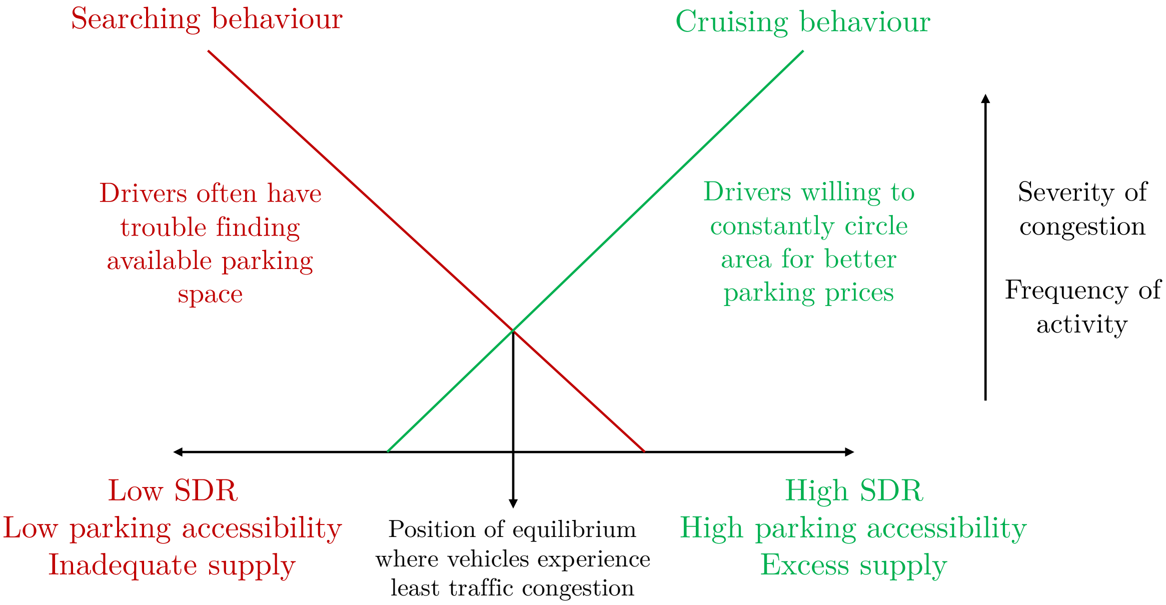


Figure 4.2. Demonstration of how the SDR of an area can influence the parking behaviour and hence severity of traffic congestion (Shoup, 2006).

Since both cruising and searching for parking behaviour require great driver attention and coordination, frequent lane-changing and abrupt changes in vehicle accelerations reduce vehicular velocity and worsen traffic congestion (Ponnambalam et al., 2018; Zhu et al., 2020). Therefore, the following set of hypotheses will be tested to validate whether parking accessibility has an impact on traffic congestion:

Null Hypothesis (H_0)	There is no correlation between the severity of traffic congestion and the accessibility to parking spaces.
Alternate Hypothesis (H_1)	There is a correlation between the severity 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]. An on-site survey will then be performed to measure the traffic congestion. Finally, both variables will be compared to validate H_1 using the Spearman Rank Correlation Coefficient (SRCC).

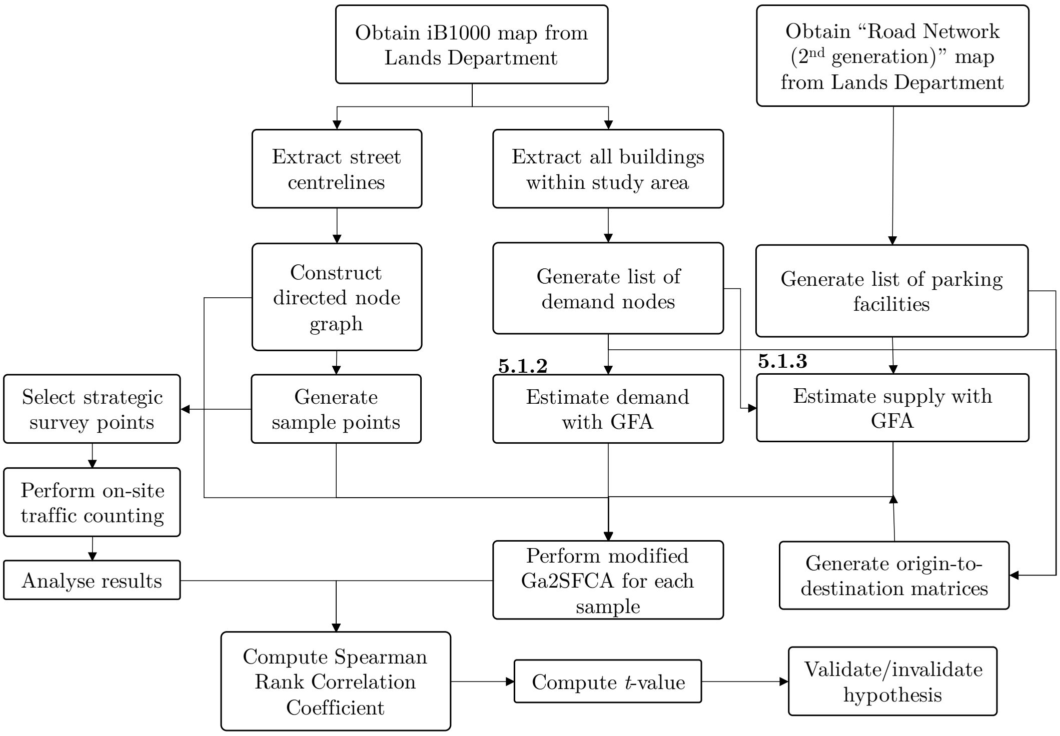


Figure 5.1. A flowchart of the general process of data extraction and processing.

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[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 A_i can be expressed by:

$$A_i = \sum\nolimits_j \frac{S_j}{D_j} \tag{5.1.1.1}$$

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 supposition that every parking facility has an equal probability of being selected is inherently untrue. 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 for by multiplying the attractiveness by some monotonically decreasing distance-decay function, with the most commonly used being Gaussian-based (Dai, 2010; Luo and Whippo, 2012; Tao et al., 2020):

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

where:

d	Distance between location and facility
d_0	Maximum catchment distance

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

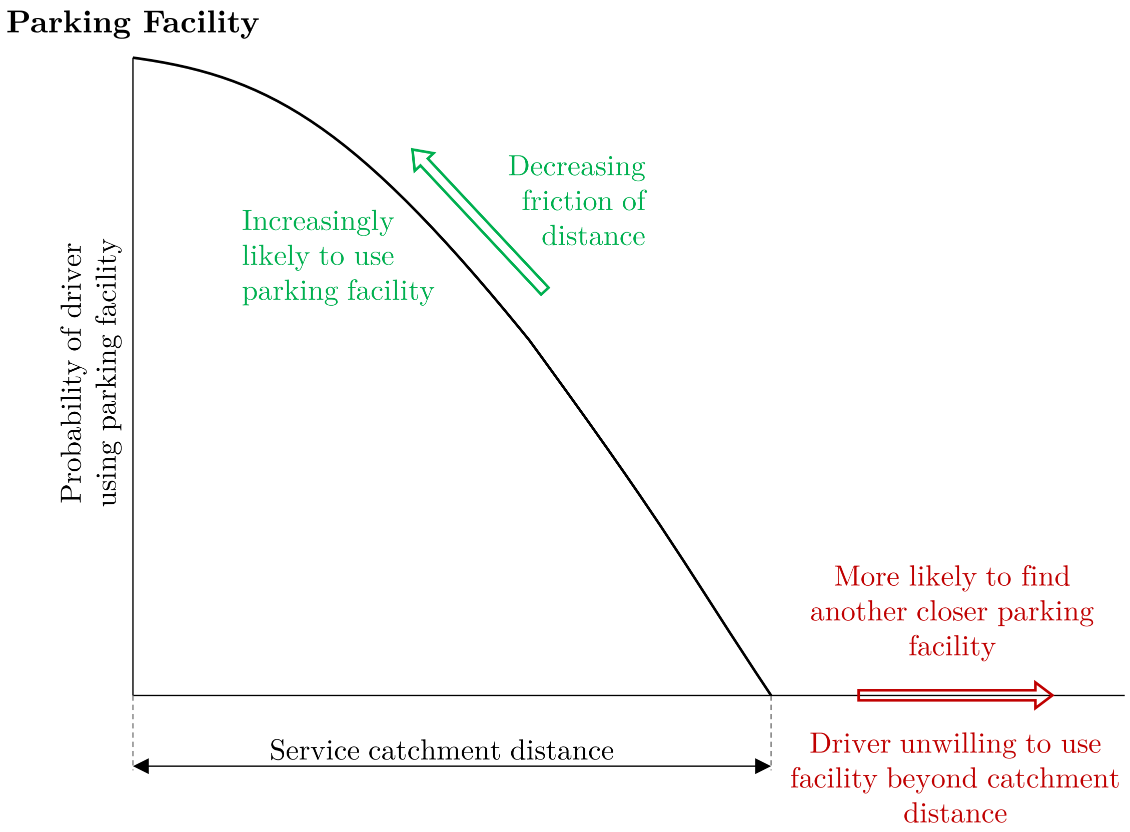


Figure 5.2. Demonstration of the distance-decay effects on the supply of parking facilities.

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 by:

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

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 to the demand:

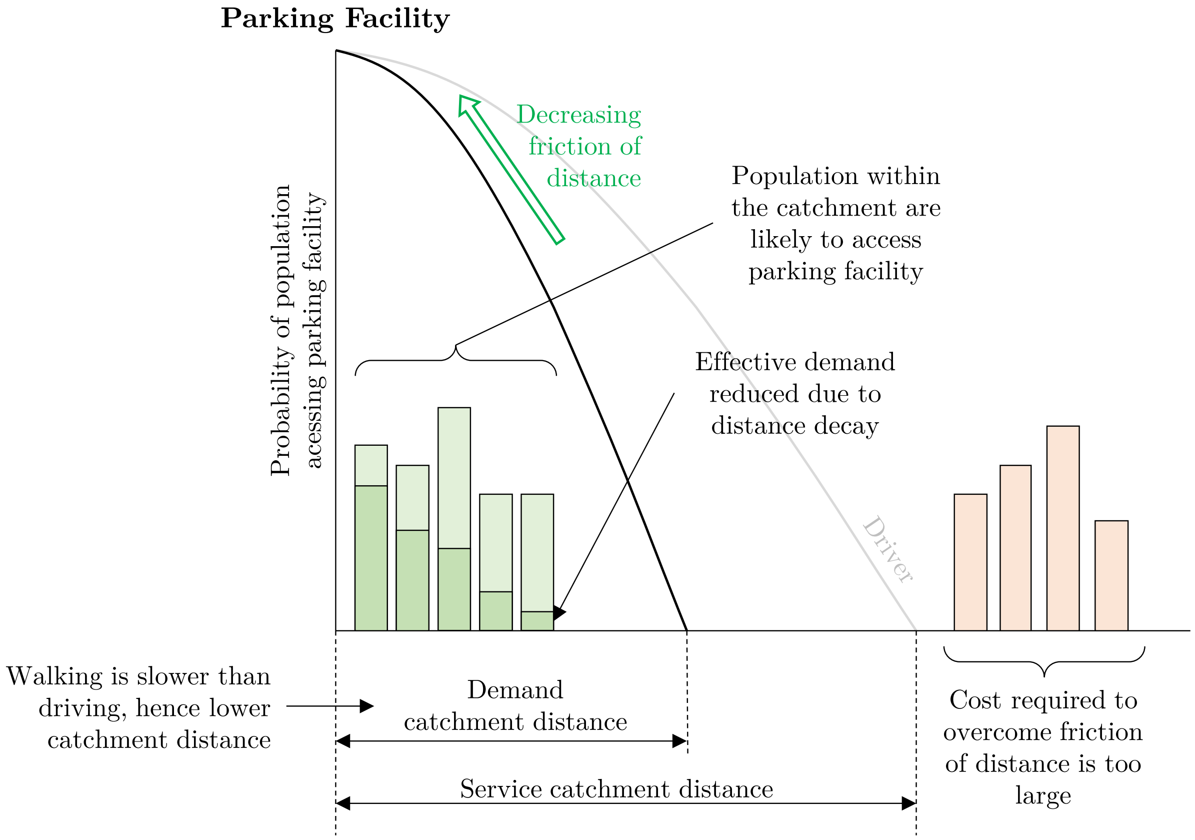


Figure 5.3. Demonstration of the distance-decay effects on the demand of demand nodes.

This yields the final equation of Ga2SFCA, accounting for both the aspatial utilisation and spatial distance-decay effects (Wang et al., 2021):

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

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

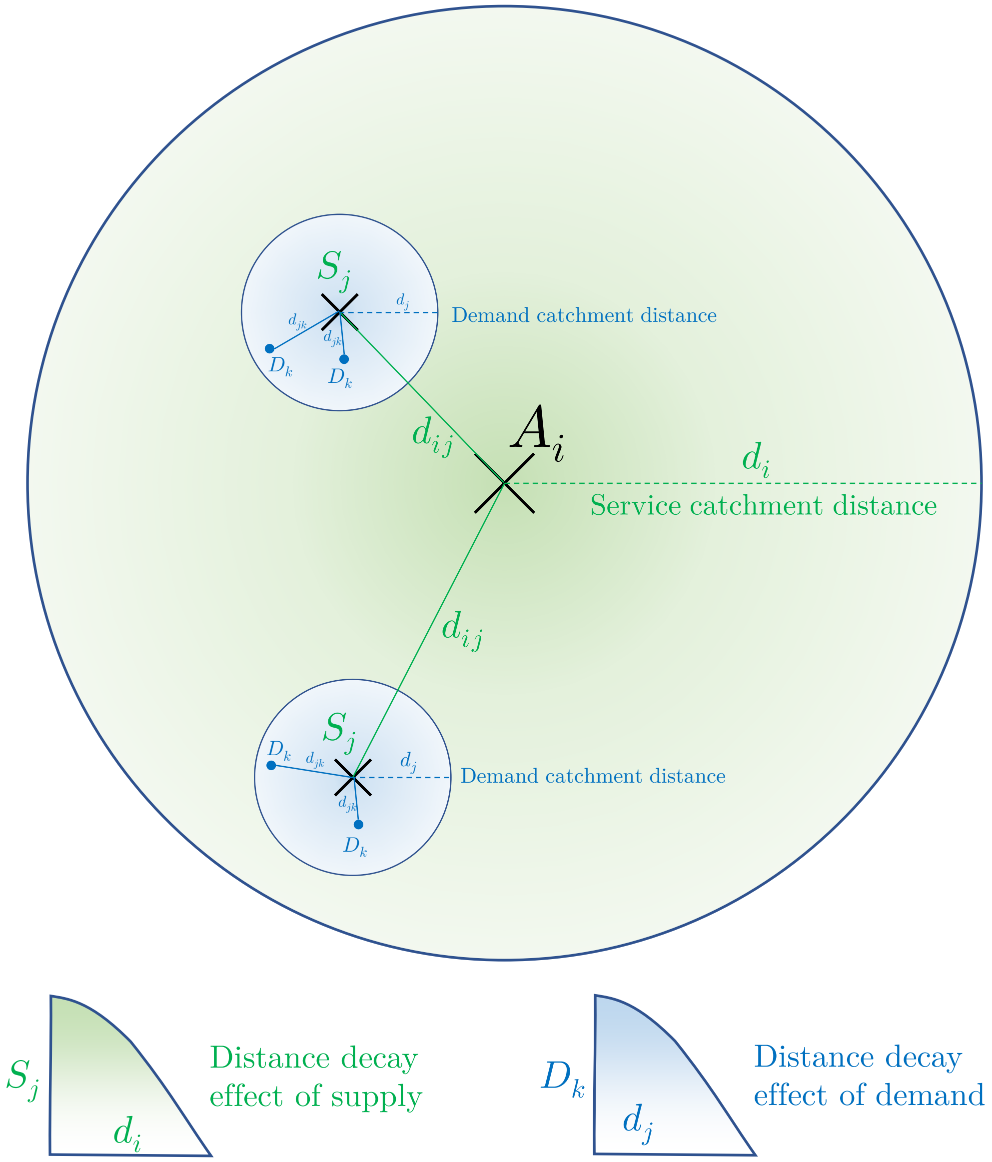
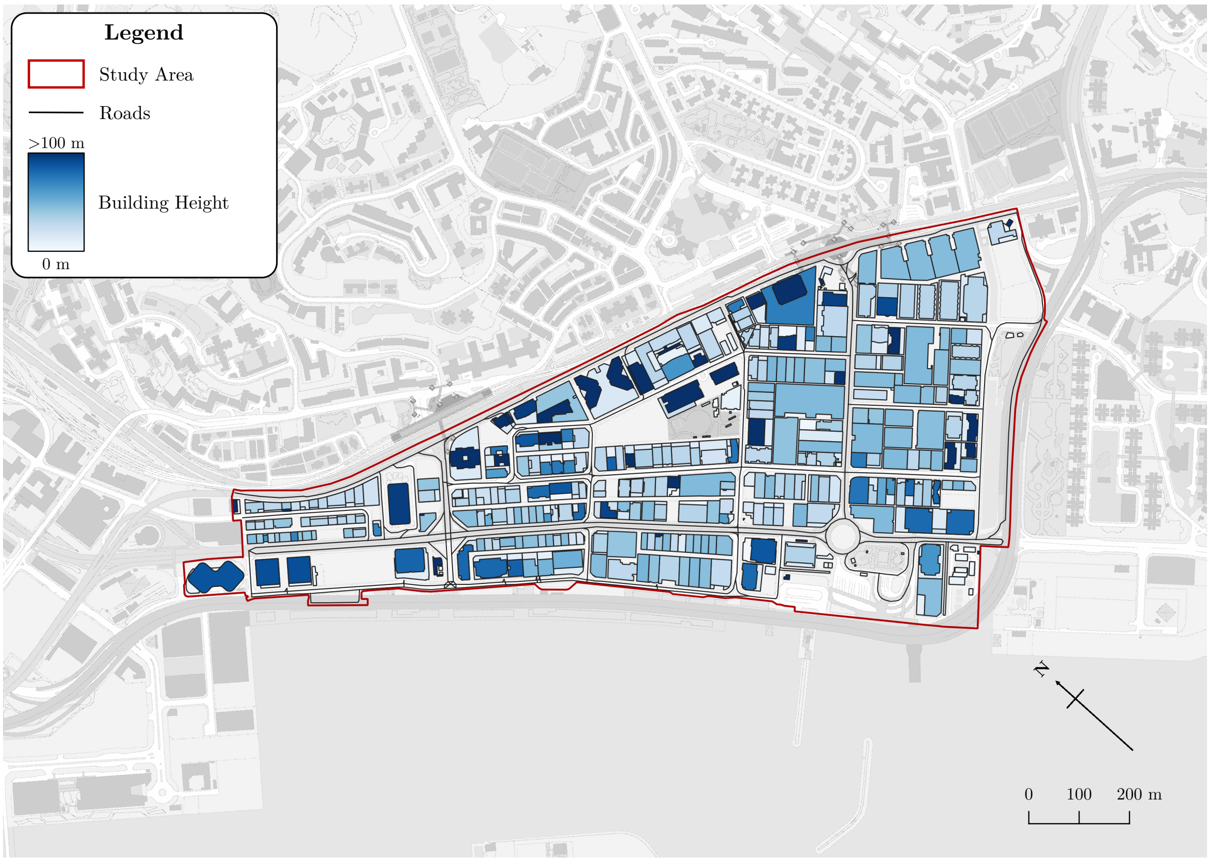


Figure 5.4. Visual representation of the modified Ga2SFCA method.

5.1.2 Quantification of demand

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

To obtain the demand (D_k), buildings are first extracted using QGIS from a digital map downloaded through the government's HKMS2.0 portal ("Lands Department", 2021):



Map 5.1. All buildings and their heights. (Hong Kong Geodata Store, 2021; Lands Department, 2021)[3]

Because the demand is strongly correlated by the number of potential users, it is closely correlated to the gross floor area (GFA) of the building, hence the relative demand is:

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

where:

$h_{rooftop}$	Height of the roof of the building (mPD[4])
h_{base}	Height of the base of the building (mPD[4])
$\overline{h_{ceiling}}$	Average ceiling-to-ceiling height of a building, which is 3.0m (Cheung, 2019)
A_{floor}	Area of each floor (m^2)

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[3] The list of all buildings and their GFAs are listed in the Appendix.

[4] mPD refers to the number of metres above the Hong Kong Principal Datum (HKPD), which is a standardised Ordnance Datum similar to the measure of "metres above sea level" (AMSL)

5.1.3 Quantification of supply

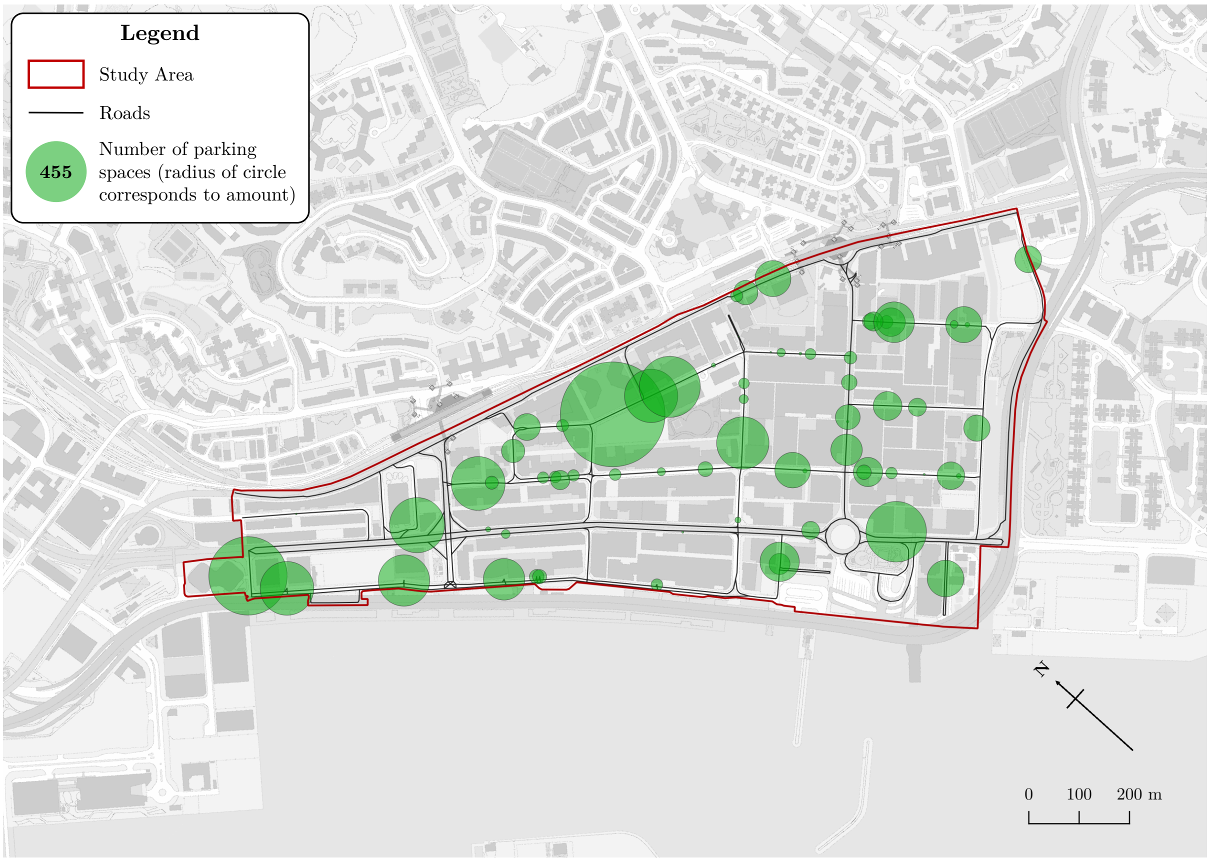
$$A_i = \sum_j \frac{S_j f(d_{ij}, d_i)}{\sum_k D_k f(d_{jk}, d_j)} \tag{5.1.1.4}$$

Since the exact number of parking spaces is not publicly available, the supply (S_j) is often estimated using parking standards which are a set of specifications newly constructed buildings must follow (Wang and Liu, 2014). According to the HK Planning Standards and Guidelines, the recommended number of parking spaces (N) for business-use buildings ("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^2), which is obtained from Section 5.1.2
n	Specific land use of the buildings, type: 'I' (industrial use) and/or 'O' (office use)



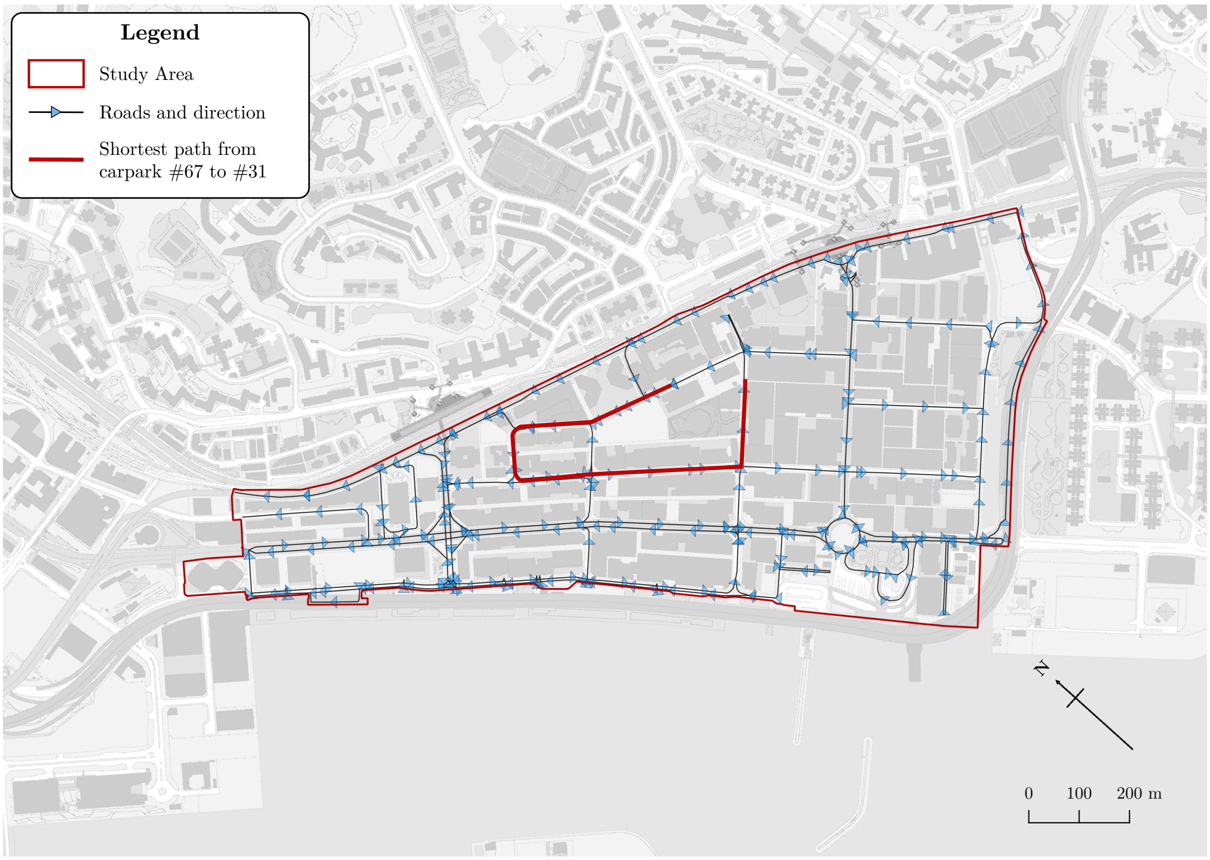
Map 5.2. Distribution of parking facilities and their amounts within the study area. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

To obtain the supply S_j, a digital "Road Network (2nd generation)" dataset is downloaded ("Lands Department", 2021) and combined with GFAs of the corresponding building, the list of parking facilities is extracted using QGIS[5].

5.1.4 Measurement of distance between locations

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

To obtain an accurate distance between two points, a weighted directed graph is generated. By using Dijkstra's algorithm, the shortest distance between two nodes could be found:



Map 5.3. A demonstration of finding the shortest distance from carpark #67 to carpark #31 using Dijkstra's algorithm. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

With Dijkstra's algorithm, two sets of origin-to-destination (OD) distance matrices are generated using QNEAT3[6] in 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})

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[5] The list of parking facilities can be found in the Appendix.

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

5.1.5 Service and catchment distance

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

The catchment distances via driving (d_j) and walking (d_i) is:

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

$$d_j = v_j t_j = \frac{62.7 \text{ m min}^{-1}}{60 \text{ s min}^{-1}} \times 2.9 \text{ min} \times 60 \text{ s min}^{-1} = 181.83 \text{ m} \tag{5.1.5.2}$$

where:

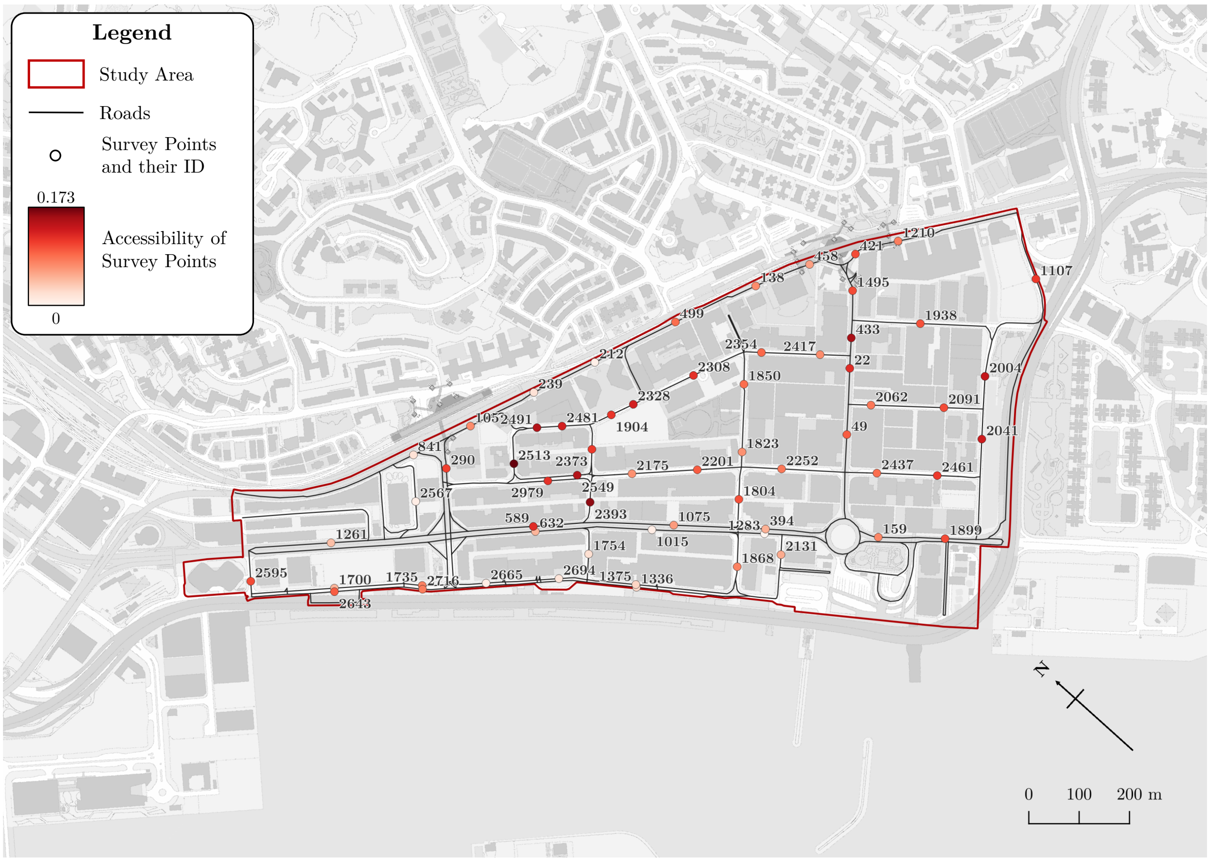
d_i	Service catchment distance of location i, by driving
v_i	Average velocity of vehicles (Transport Department, 2021)
t_i	Average search time of vehicles (Lau et al., 2005)
d_j	Population catchment distance of demand node j, by walking
v_j	Average velocity of pedestrians in KT (Master Alliance Ltd., 2021)
t_j	Average search time of pedestrians (Lau et al., 2005)

5.1.6 Sampling method

To maximise data representativeness and to reduce the time needed to collect samples, stratified sampling is used, where each major road segment is sampled between 1-2 times. The following constraints are set to maximise data accuracy:

- should be as evenly distributed as possible to maximise data variability and to avoid neighbouring values
- should not be located within proximity to intersections, 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 5.4.



Map 5.4. The distribution of selected sample points and their accessibility index A_i. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

5.2 Traffic congestion

With traffic speed being an excellent proxy indicator for traffic congestion, it 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 web application is developed to collect both parameters.

5.2.1 Time-occupancy

Time-occupancy is defined as:

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

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).

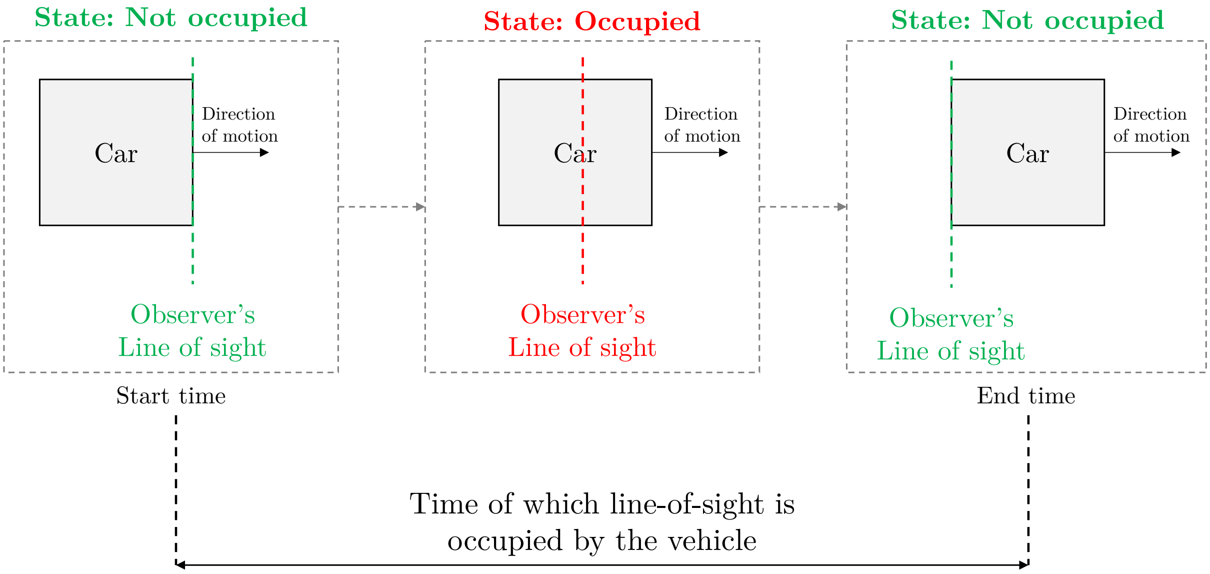
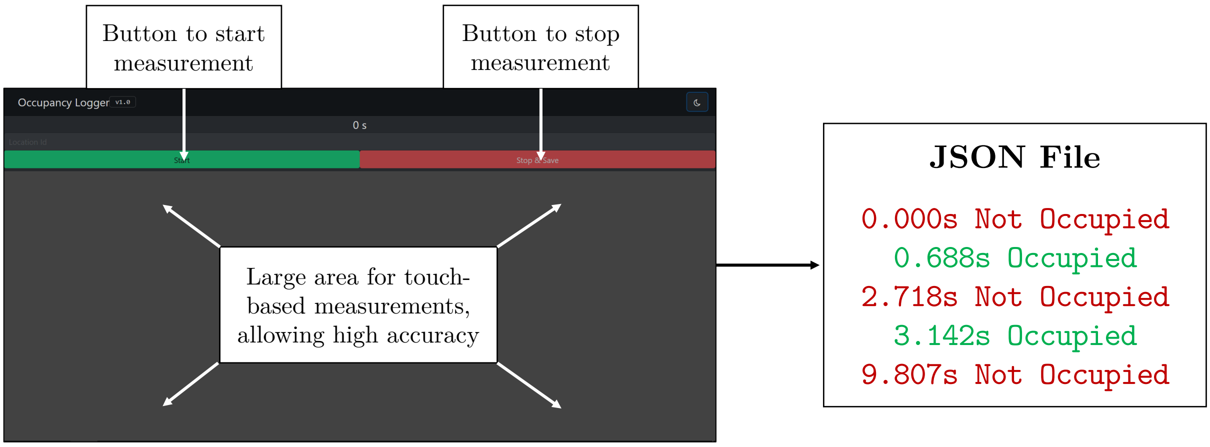


Figure 5.6. Visual representation of how time-occupancy is calculated.

The web interface is designed to operate on a touch-enabled smartphone[7], which will save touch measurements in a JSON file[8] containing timestamps that describe the occupancy at that instant:



```
0.000s Not Occupied
0.688s Occupied
2.718s Not Occupied
3.142s Occupied
9.807s Not Occupied
```

Figure 5.7. The interface of the 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) can be derived by counting the number of "`Occupied`" states in Figure 5.7[9].

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

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

[9] 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

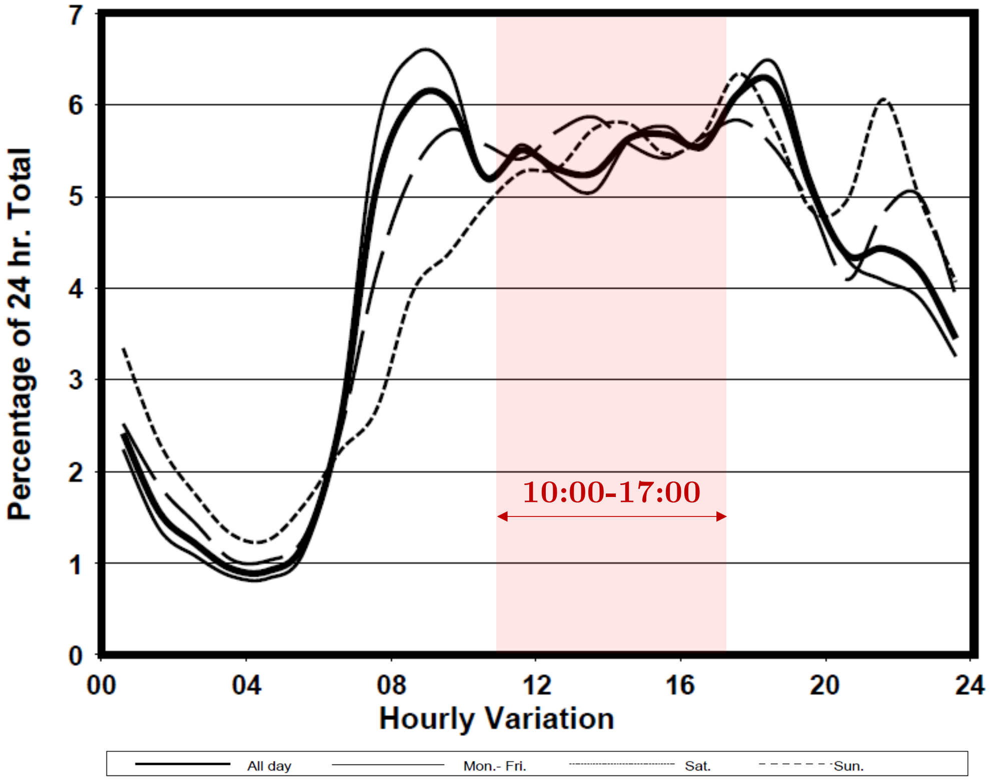


Figure 5.8. Graph of daily and weekly traffic changes of the Kwun Tong District, at Station #3012 (Transport Department, 2021).

To reduce data fluctuations, surveying shall be performed from 10:00-17:00 because the traffic flow is rather stable, has a sufficiently large volume, and is the time when economic activities are the most active (Labour Department, 2013). The surveying shall be completed on a single day to reduce the effect of unpredictable events (such as weather) on the rate of traffic generation.

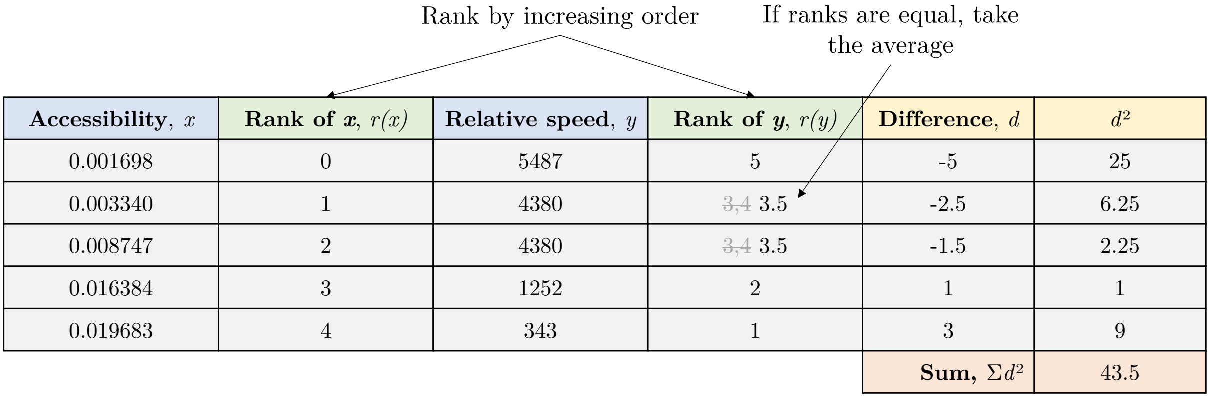
5.4 Hypothesis Testing

5.4.1 Spearman Rank Correlation Coefficient (SRCC)

An SRCC test is used to determine the magnitude of two variables. The SRCC is insensitive to outliers and produces highly accurate measures of correlation especially for nonlinear relationships (Lovie, 1995). It 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 x**, $r(x)$	**Relative speed**, y	**Rank of 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, Σd^2	43.5

Figure 5.9. A table for calculating $\sum d^2$ from the accessibility (x) and relative speed (y).

Figure 5.10. A general interpretation of the correlation based on the SRCC.

5.4.2 Student's T-test

To check whether the SPCC obtained is statistically significant enough to reject H_0, 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 be found by obtaining the two-tailed p-value:

$$p = 2\int_t^\infty f(u)\,du \tag{5.4.2.2}$$

where f is the probability density function and t the t-value. When $p < 0.05$, H_0 can be rejected.

6 Data Analysis

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 is used. In addition, a bivariate dot map is used to visualise the geospatial patterns of both variables.

6.1 Macroscopic Trend

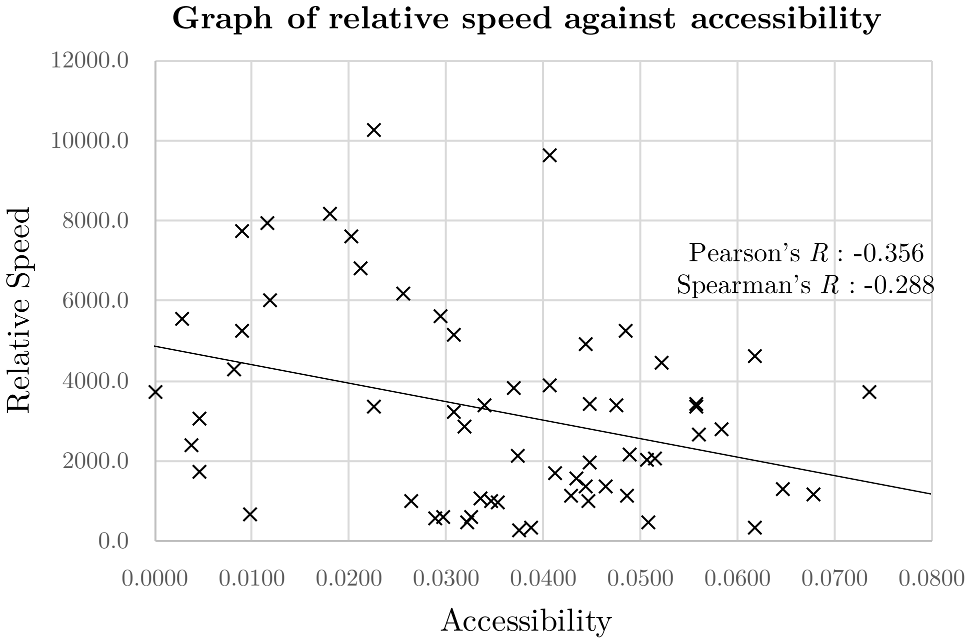


Figure 6.1. A scatter graph showing the relationship between relative speed against accessibility.

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	0.0232
Null hypothesis rejected?	Yes, as $p < 0.05$	

Table 6.1. Statistics regarding the Spearman's rank correlation testing.

As the SRCC is -0.288, there is a very weak negative correlation between the speed and 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 H_1 has been accepted statistically, the poor reliability of the correlation cannot be used to definitively conclude that parking accessibility is the *only causation* of traffic congestion (Coleman et al., 2015), and additional qualitative justification is required to describe the relationship between the two variables.

6.1.1 Heteroscedasticity

In regression analyses, it is assumed that dependent variables are homoscedastic, meaning a constant variance (σ^2).

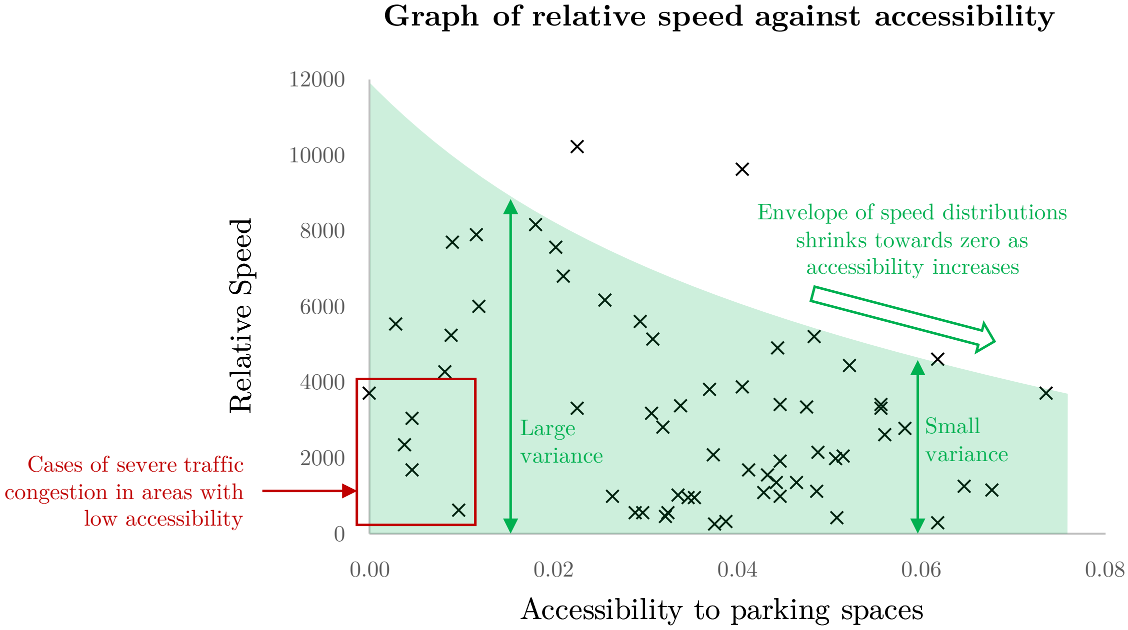
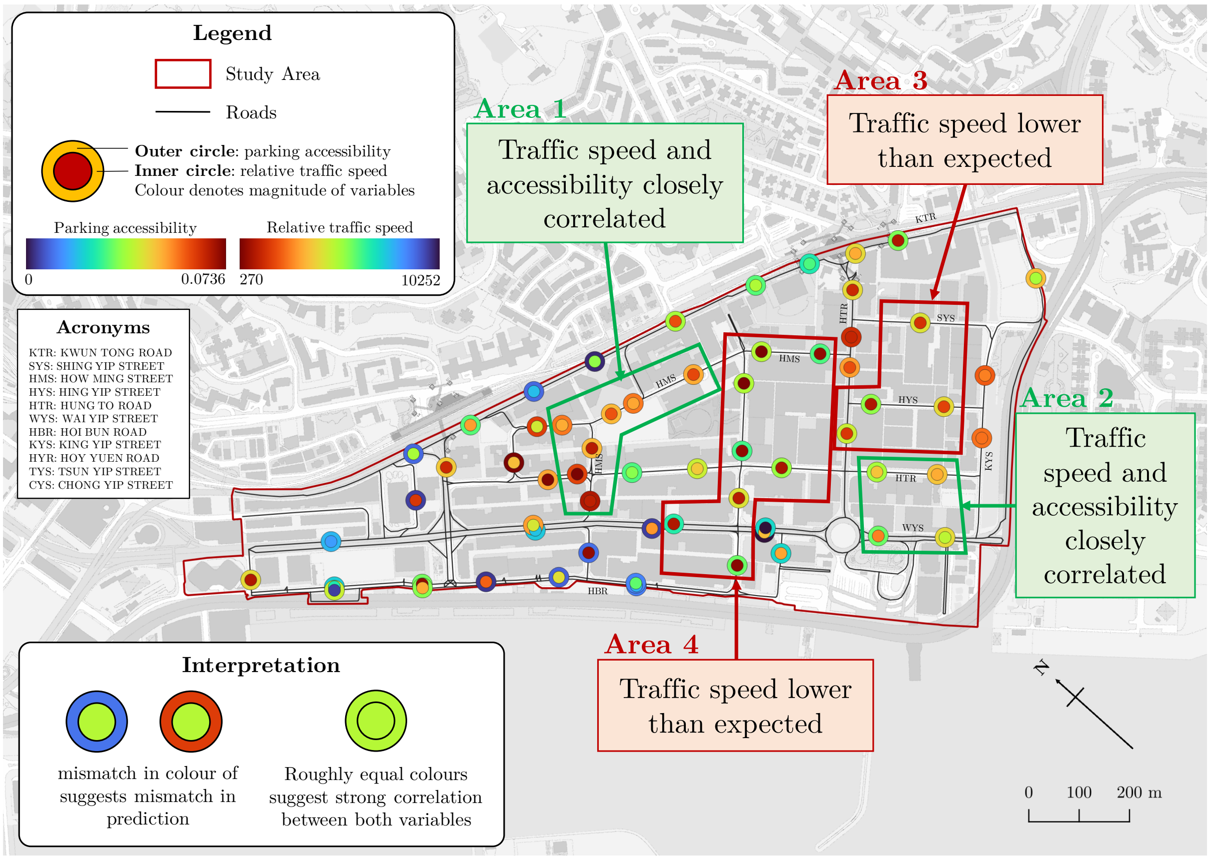


Figure 6.2. Demonstration of how heteroscedasticity can contradict the acceptance of H_1.

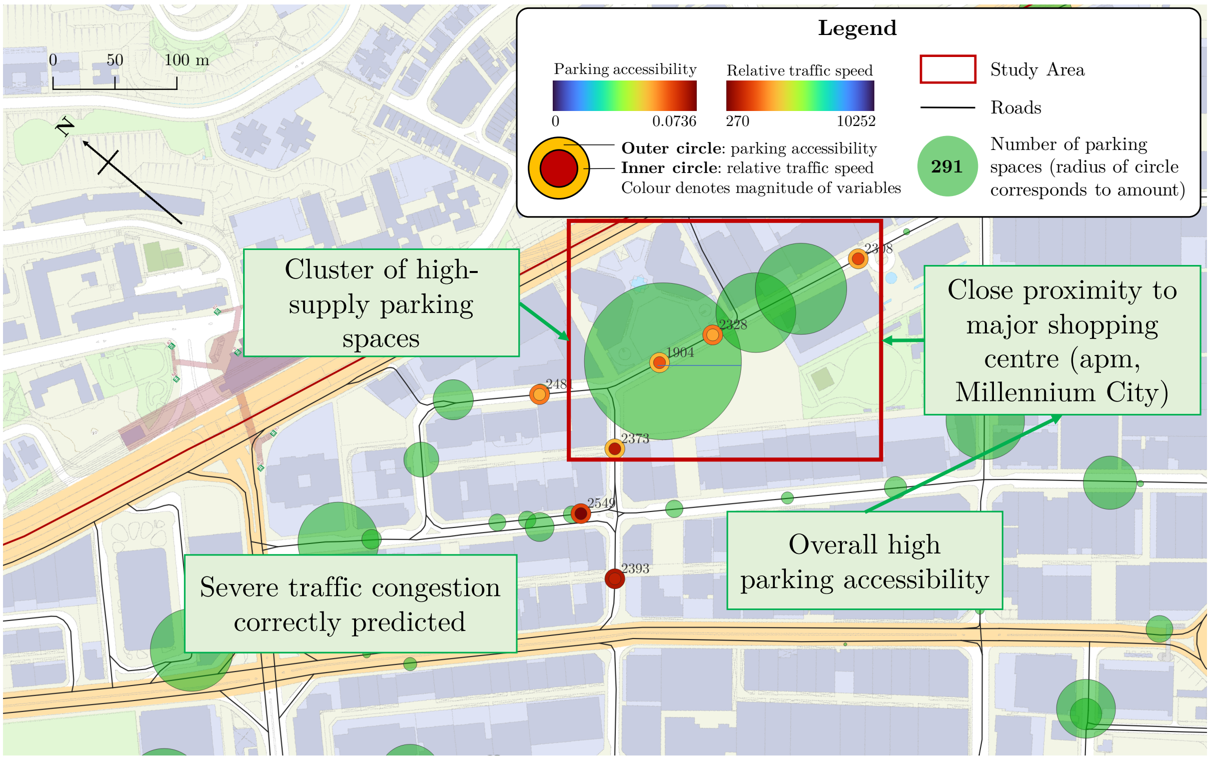
However, the above shows that the variance of speed is unequal. As Goldberger (1964) suggests, heteroscedastic data can cause Type I errors in hypotheses testing, where H_0 is falsely rejected.

If 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 inaccurate because such phenomenon occurred multiple times. It would therefore be more accurate to interpret the data by the statement: “there may be a greater probability of experiencing less traffic congestion in areas with low parking accessibility”.

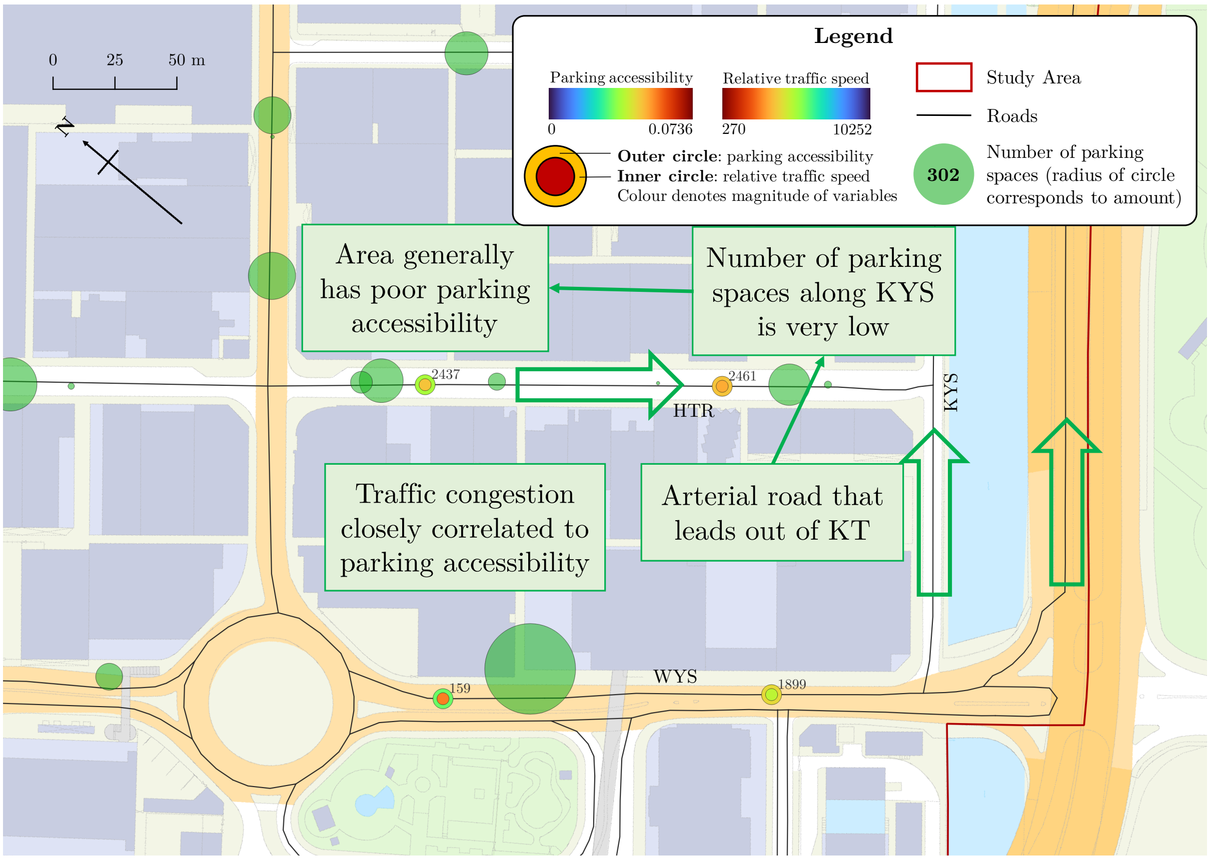
6.2 Qualitative Analyses



Map 6.1. A bivariate dot map showing the accessibility and speed of survey locations. (Hong Kong Geodata Store, 2021; Lands Department, 2021)



Map 6.2. A map showing how the traffic speed is correctly predicted in the heavily congested Area 1. (Hong Kong Geodata Store; Lands Department, 2021)



Map 6.3. A map showing how a smooth traffic flow has been correctly predicted in Area 2. (Hong Kong Geodata Store; Lands Department, 2021)

The maps above show the spatial distribution of survey locations and the extent of each variable. There are several notable areas where both variables are strongly correlated, as highlighted in Areas 1 and 2.

In Area 1, it has been hypothesised that because of the overabundance of parking spaces offered at shopping centres, it attracts a large number of vehicles to the area. When this happens, the road becomes increasingly oversaturated with additional cars and therefore causes traffic congestion.

In Area 2, because HTR, WYS and KYS are all centrifugal roads that exit KT and combined by the lack of parking spaces in the area, the severity of traffic congestion is expected to be low, because vehicles travelling at WYS are typically leaving KT. Since the predictions match the observations in areas of both high and low parking accessibility, H_1 is supported.

However, as observed in Map 6.1, there are some notable large-sized areas (Areas 3 and 4) where the severity of traffic congestion is underestimated. Given that the area and extent of the macroscopic anomalies appear to as large as the area that validates H_1, it is equally as important to investigate whether there are external factors that may have contributed to the deviation.

6.2.1 Role of land use in traffic congestion

While it has been assumed that vehicles will always unload goods and people at parking facilities, on-site observations reveal that vehicles often stop at locations that cause inconvenience to other road users:

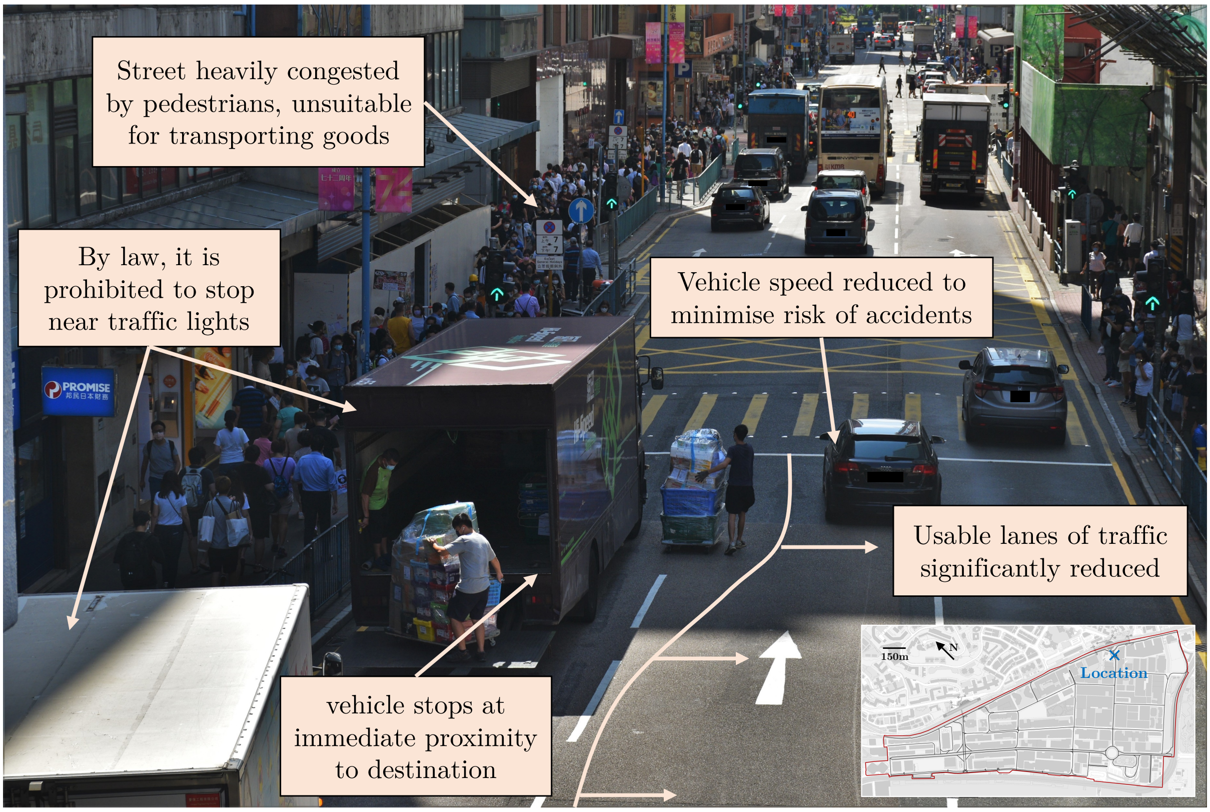


Figure 6.3. Demonstration of industrial vehicles obstructing traffic flow. (841349,819187$^{\text{EPSG:2326}}$)

This behaviour can be attributed to the fact that the area is heavily industrial, where there is great demand for the import of raw materials and export of manufactured products, leading to high volumes of medium goods vehicles (MGV). Because heavy goods are unsuitable for long-distance travel by foot and combined with the lack of movable space in pavements, incoming trucks often unload goods within immediate proximity to their destination to maximise convenience. With logistical efficiency a key to the economic success of an industrial company, drivers are unlikely to spend the additional time and cost to search and use a dedicated parking facility. Therefore, it can be said that in industrial districts, the assumption that drivers will consider of parking accessibility when unloading goods is weak.

In addition, the result of unloading goods in a moving stream of traffic reduces the effective number of lanes, forming a bottleneck that worsens traffic congestion. Furthermore, by obstructing the vision of traffic lights (see Figure 6.3), it further reduces the cognitive ability for drivers to determine the traffic signal and hence reduces vehicular speed and increases sporadic accelerations, overall introducing congestion.

The phenomenon of industrial-based vehicles not using parking facilities can also be observed by illegal and double parking:

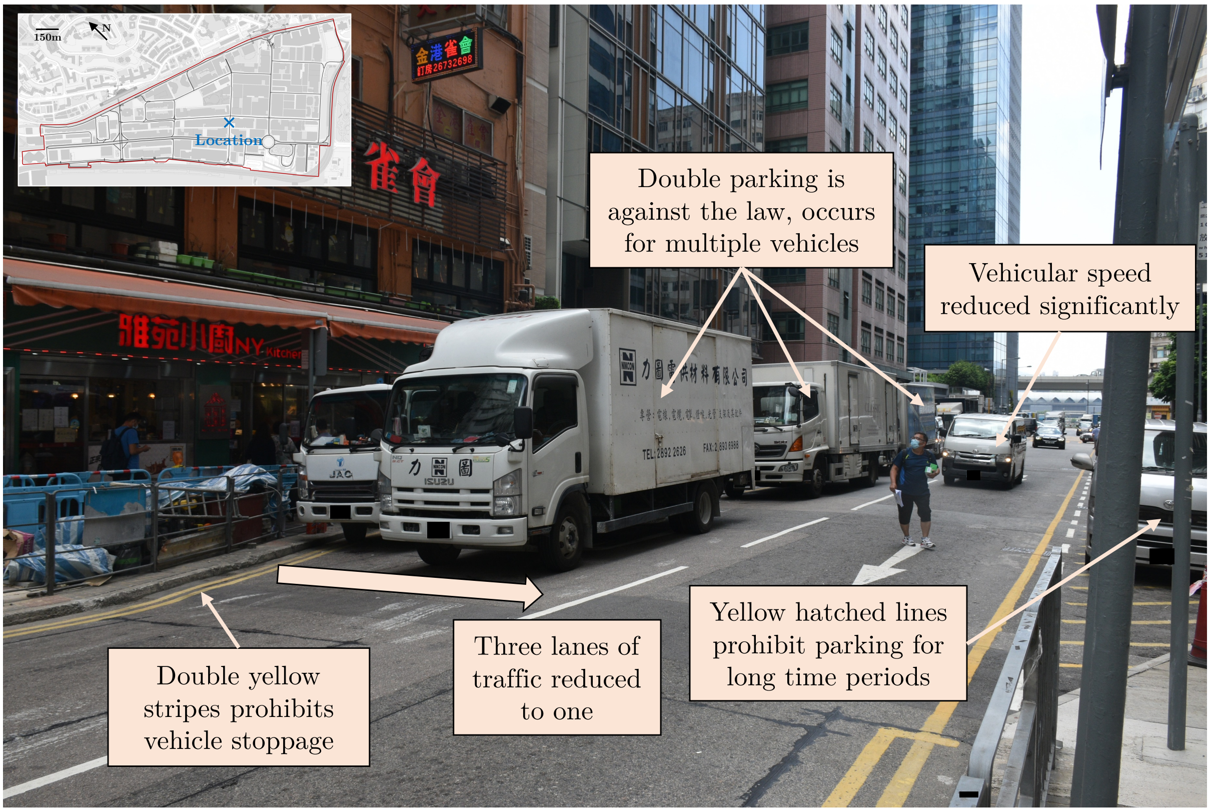


Figure 6.4. Photo of MGVs violating multiple parking restrictions. (*"Cap 374C"*, 2021; 840899,819090$^{\mathrm{EPSG:2326}}$)

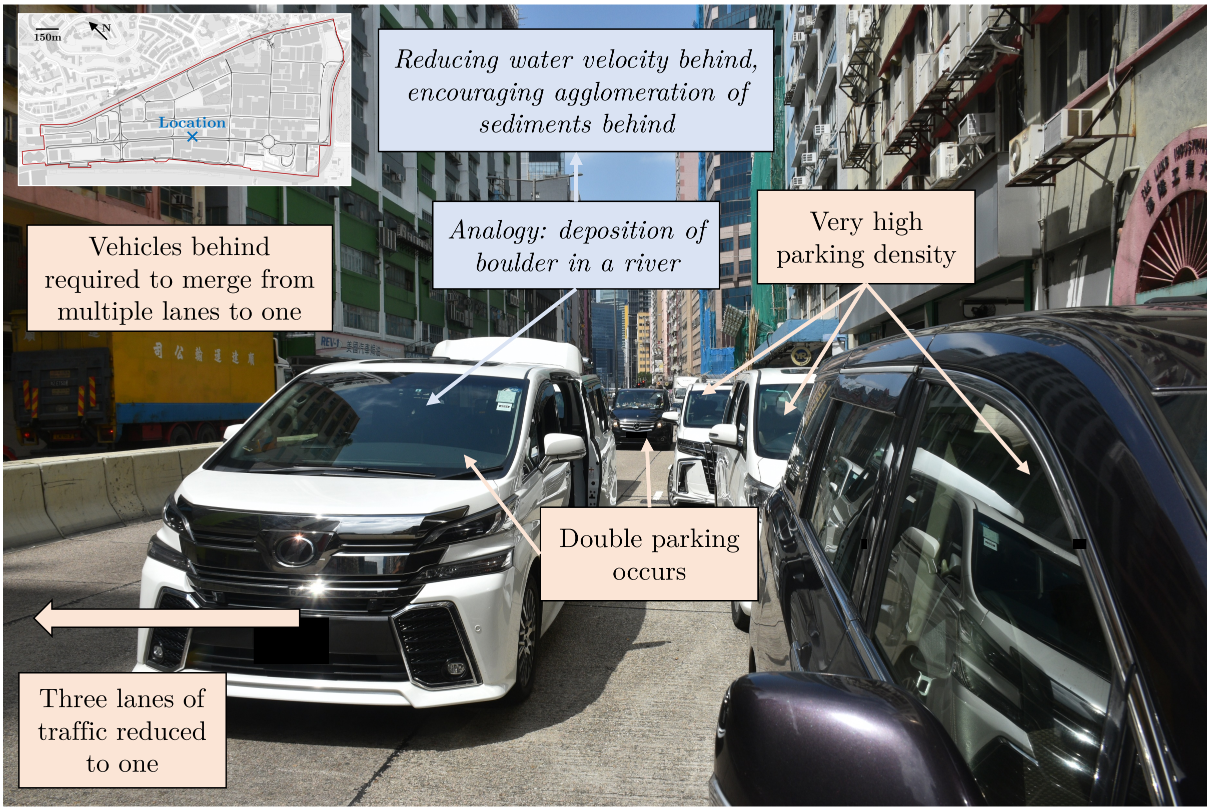


Figure 6.5. Demonstration of how double parking can encourage further double parking and worsen traffic congestion. (*"Cap 374C"*, 2021; 840727,819155$^{\mathrm{EPSG:2326}}$)

As seen above, a multitude of parking restrictions has been violated. To explain the cause, drivers often perform a risk assessment to determine whether they are willing to neglect traffic restrictions to trade for convenience.

When the probability of receiving a fine is lower than the operational costs incurred from encircling the area, the desire for parking illegally will be increased. Because industrial vehicles have a strong motive to maximise profit by increasing the throughput of supplies and materials and to ensure the stability of the supply chain, journeys relating to logistics are often time-sensitive. The driver's preference is therefore strongly influenced to minimise movement over avoiding fines, hence leading to the common occurrence of illegal parking (Nurul Habib et al., 2011).

Other than vehicle stoppage inducing traffic congestion, delivery workers from industrial vehicles also exacerbate traffic congestion:

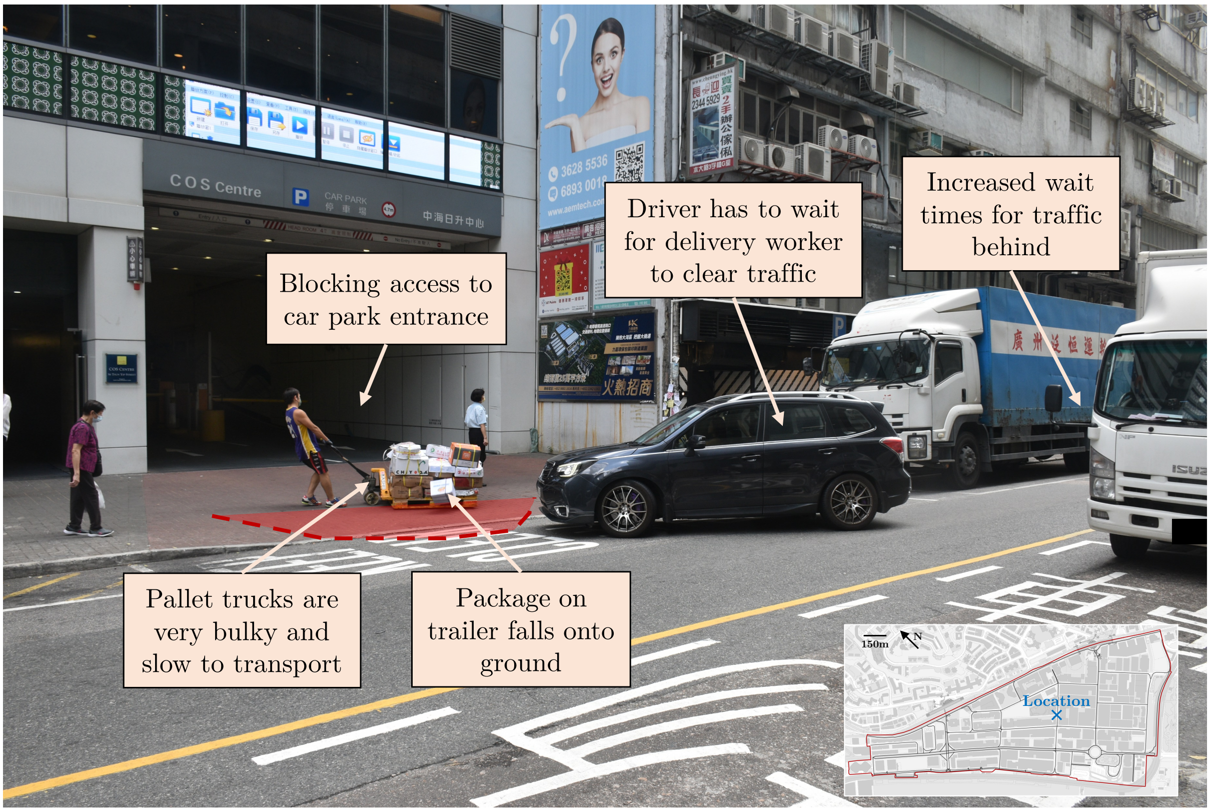


Figure 6.6. Photo of delivery workers blocking the entrance to a car park. (840967,819144$^{\mathrm{EPSG:2326}}$)

Because delivery workers often transport a large number of bulky goods with trailers to shorten delivery times, their movement speed is often very slow. Combined with the fact that KT is a highly concentrated industrial district, this phenomenon occurs region-wide:

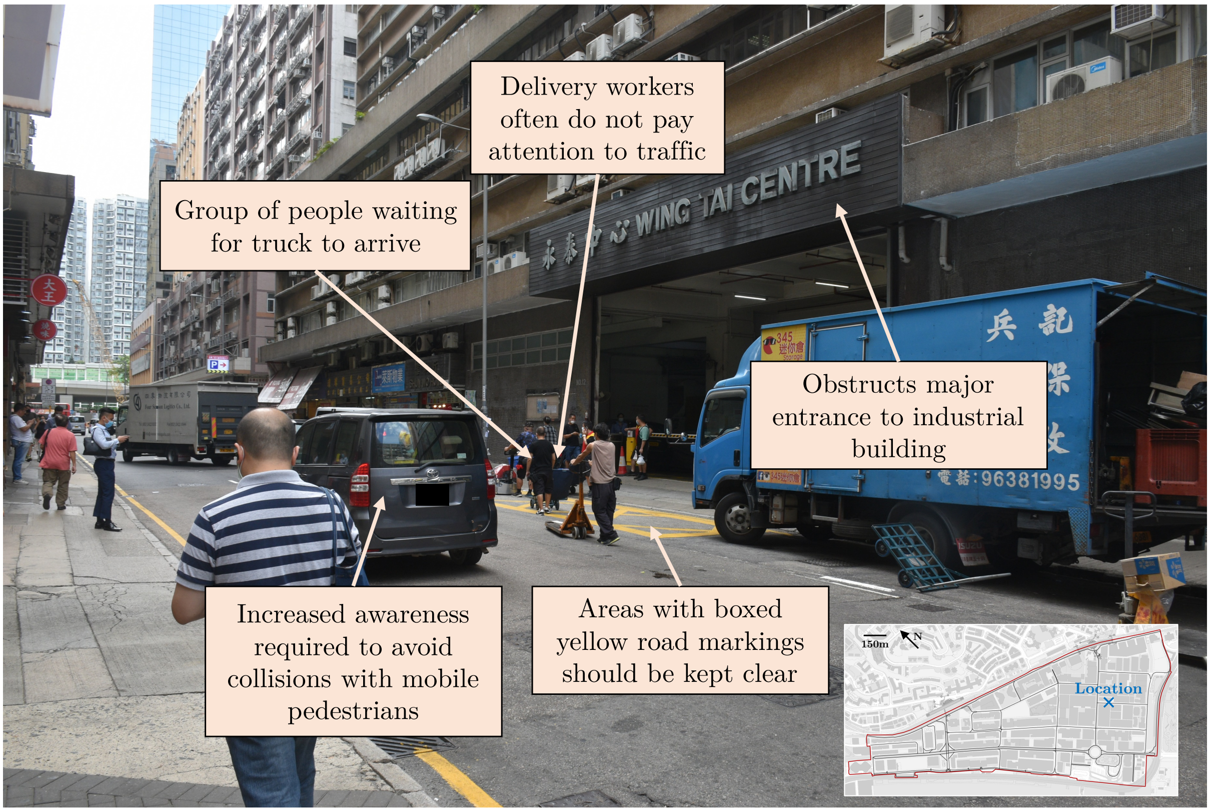


Figure 6.7. Photo of a group of delivery workers congregating, indirectly reducing traffic speed. (841204,818978$^{\text{EPSG:2326}}$)

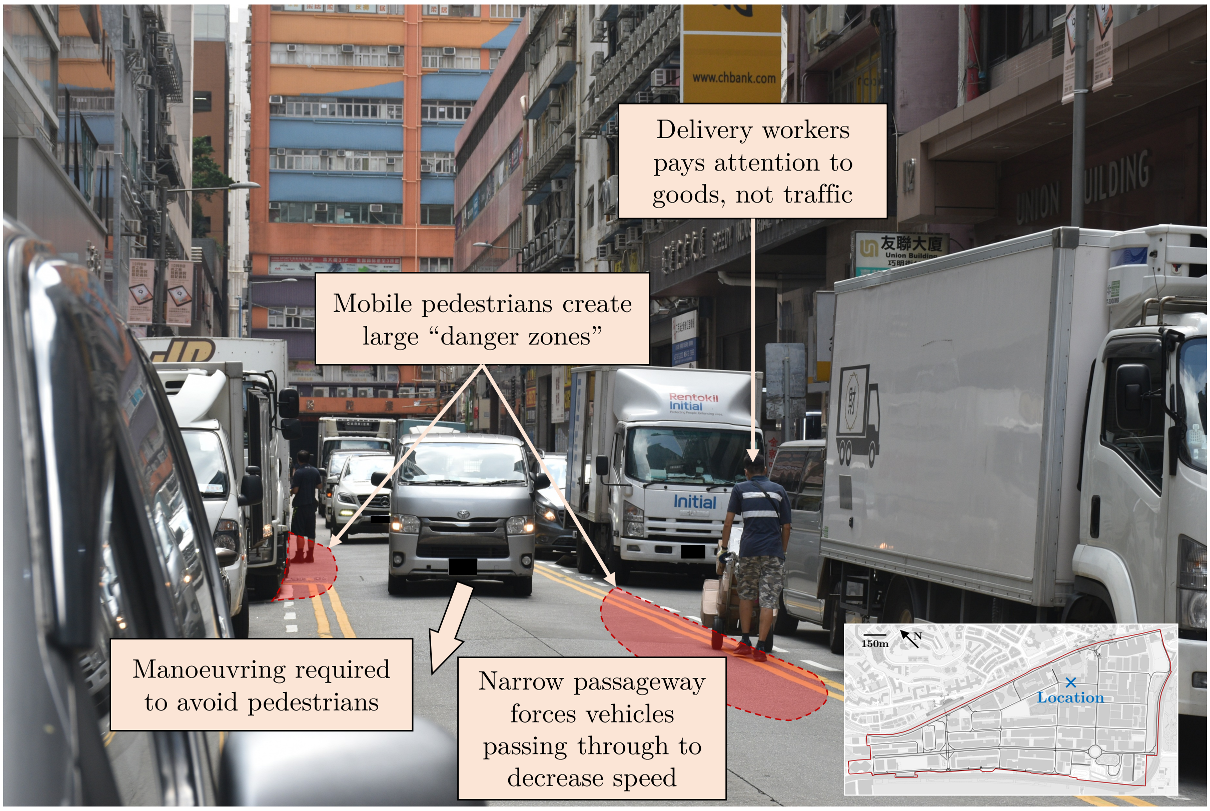


Figure 6.8. Demonstration of how mobile pedestrians cause drivers to slow down significantly. (841140,819200$^{\text{EPSG:2326}}$)

Overall, because KT is predominantly composed of industrial buildings, vehicles involved in industrial activities do not have the necessity or benefit of finding or using a parking facility, therefore resorting to illegal parking, and contributing to traffic congestion.

Conversely, vehicles that serve other land-use types such as commercial and retail purposes instead have a strong and regular will of patronising a parking facility. For example, because people engaged in shopping activities have a limited personal budget, there is a strong incentive to avoid illegal parking (Mingardo and van Meerkerk, 2012). Similarly, because white-collar workers engaged in office activities only ever work at a single location, the attractiveness of repeatedly utilizing the same parking facility is enormous. The usage of parking facilities can be even further increased by parking vouchers, monthly-reserved parking packages or employer subsidies (Lam et al., 1998).

Therefore, given that the nature and goal of industrial activities are fundamentally different from other activities, varying both in budget and obligation of using parking facilities, it can be argued that land use strongly governs the severity of traffic congestion, much more so than parking accessibility.

6.2.2 External physical factors and limitations

Other than land-use effects, there are several factors that further cause vehicles to ignore their accessibility to parking spaces, and rather choose to stop at their immediate location. One of which is the deliberate obstruction of on-street parking spaces with barricades:

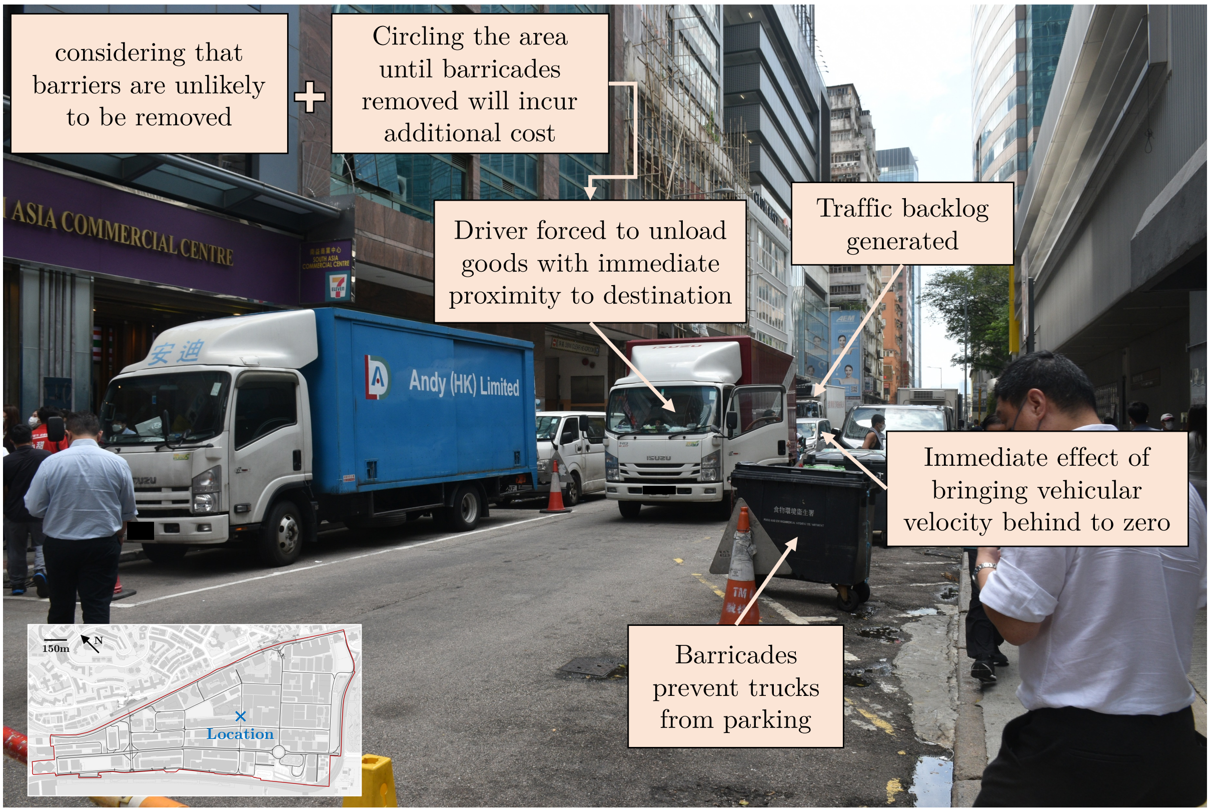


Figure 6.9. Photo of an HGV being forced to unload goods due to barricades obstructing the alighting zone. (841140,819200$^{\text{EPSG:2326}}$)

Figure 6.10. Photo of how physical barricades indirectly obstruct traffic flow and worsen traffic congestion. (841058,819220$^{\mathrm{EPSG:2326}}$)

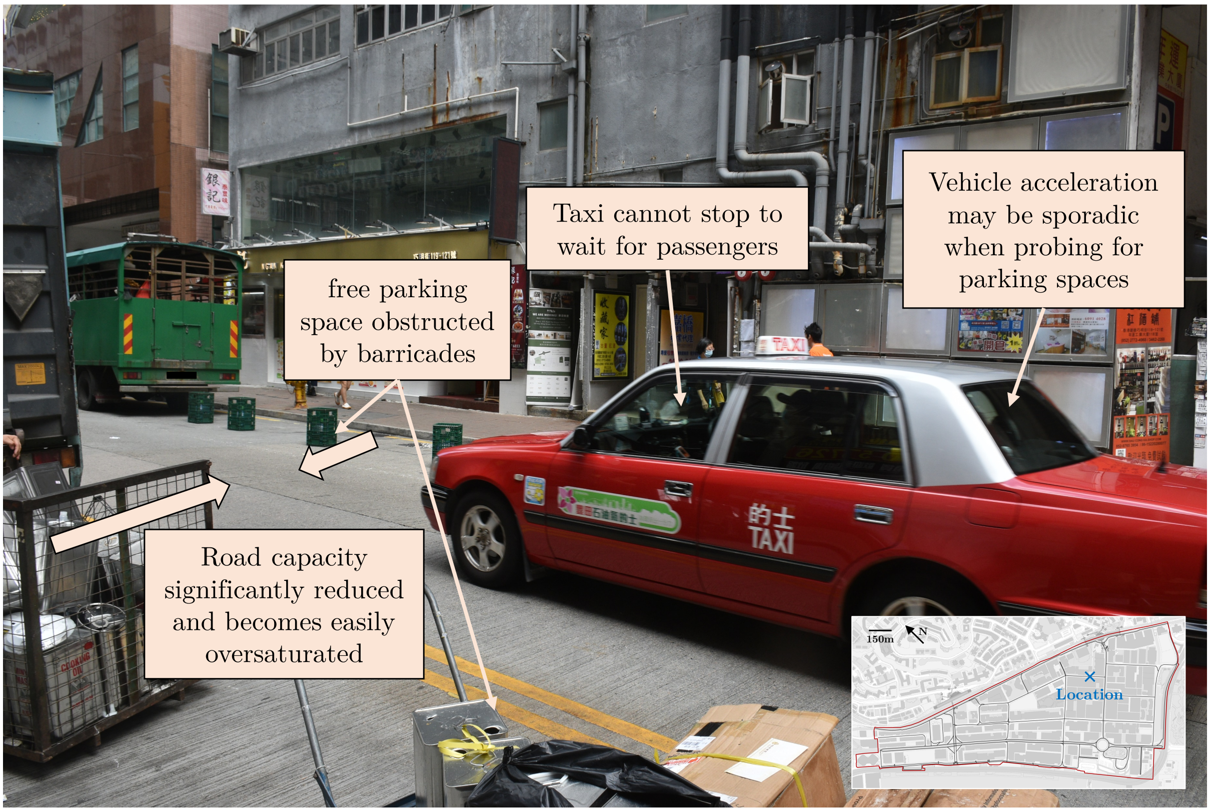
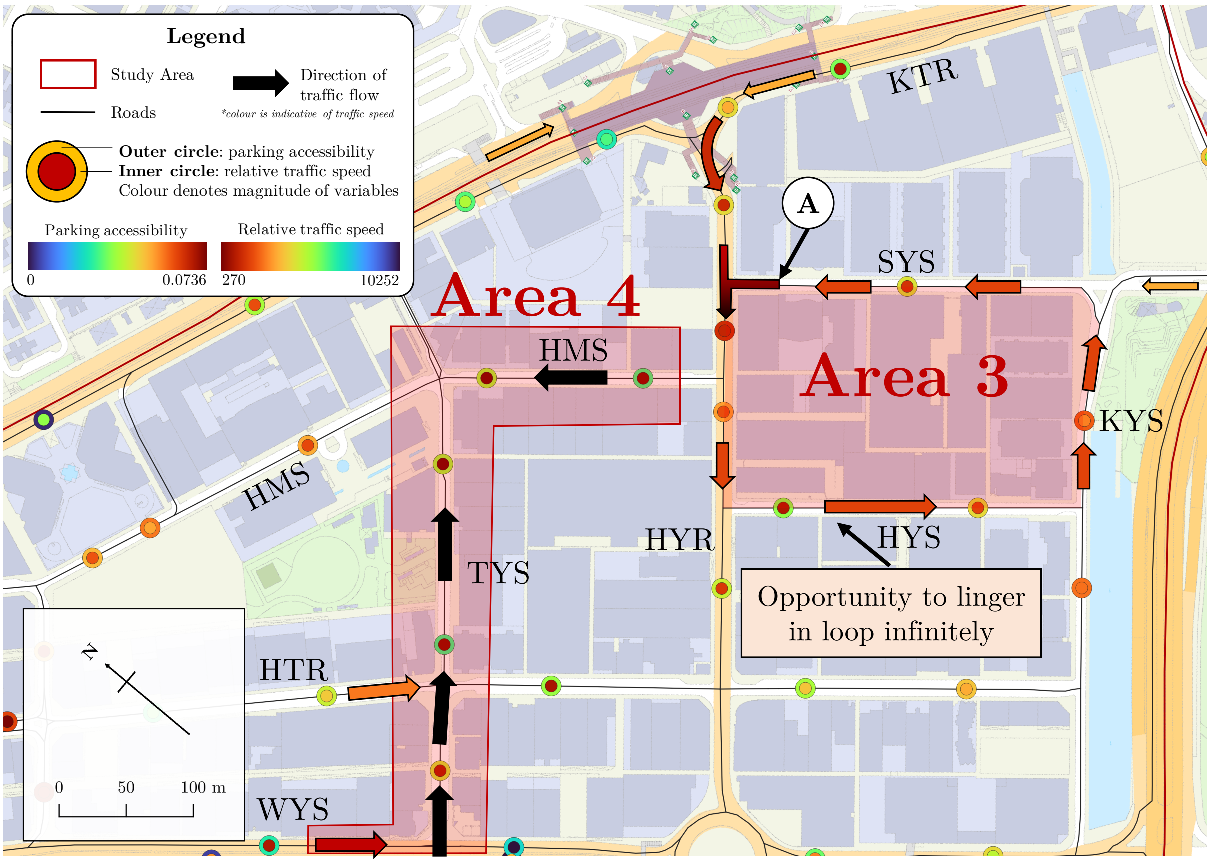


Figure 6.11. Demonstration of how physical barricades impede the normal operations of a taxi. (841058,819220$^{\mathrm{EPSG:2326}}$)

From the above, the fact that such barricades (rubbish bins, trolleys, and light cartons) are highly mobile suggests that they are used for pre-reservation purposes, which causes incoming traffic to be forced to stop at the only available lane. According to Li et al. (2019), sudden traffic halts can propagate quickly downstream and across street grids, hence explaining why the entire length of TYS is unusually congested.

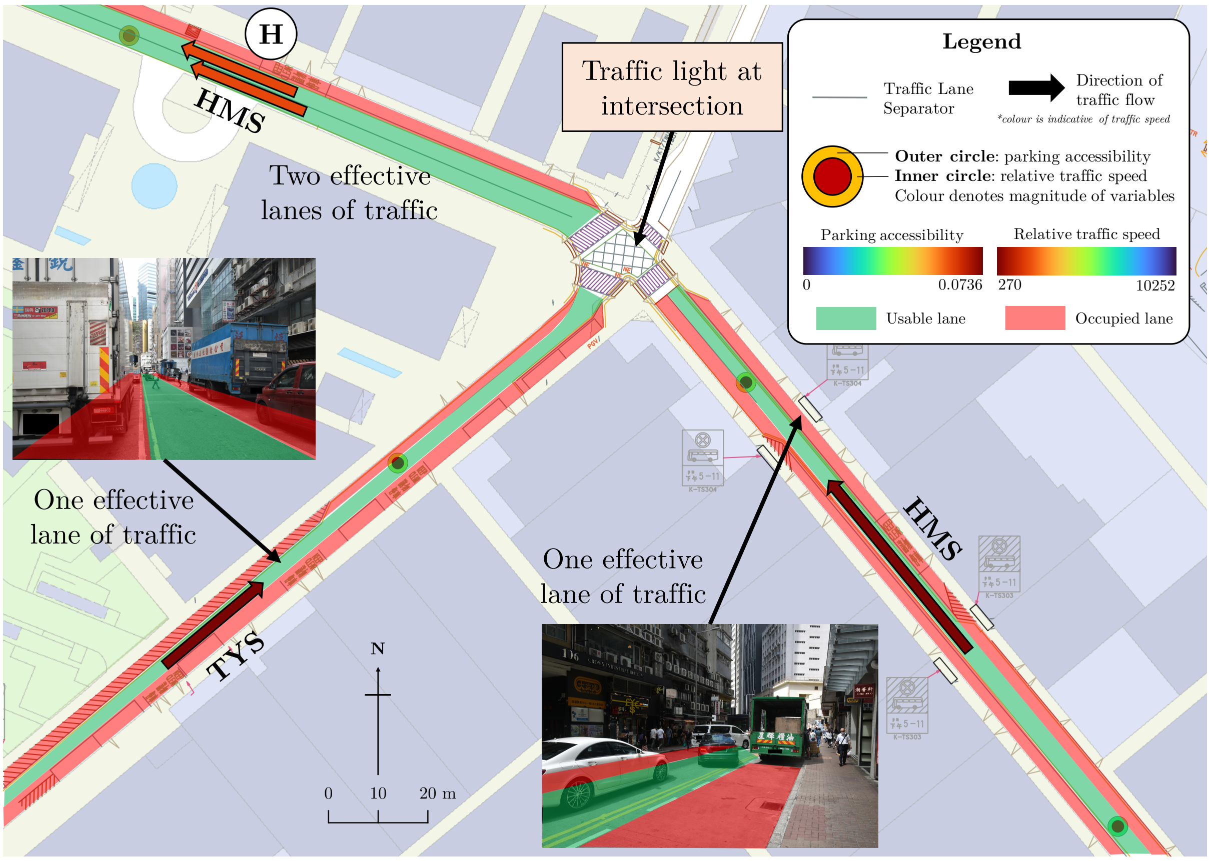
Although the law specifically prohibits the obstruction of parking spaces (*“Cap 374C”*, 2021), for one to willingly violate regulations just to secure a parking spot reflects that parking availability is extremely scarce and competitive among road users. Because there is a region-wide insufficiency of parking space, it is inaccurate to conclude that “supply imbalances of parking facilities cause traffic congestion”, because all parking facilities are observed to have close-to-zero supply.

Furthermore, KT is the oldest industrial district in HK. Given the road layout have remained largely unchanged with the traffic flow continuously increasing (Traffic Department, 2021), several routing issues with the current road layout have been identified:



Map 6.2. Map of the two most visually distinct over-congested regions. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

In Area 3 above, it has been observed that SYS, HYR, HYS and KYS forms a closed anti-clockwise loop of traffic. This enables drivers to encircle the area infinitely, and combined with the increasing traffic from KTR, the traffic stress is very high. In Area 4, TYS and HMS appear to have severe traffic congestion, seemingly because they merge into one lane. Below is a closer view of the location:



Map 6.3. Map of the intersection between How Ming Street and Tsun Yip Street. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

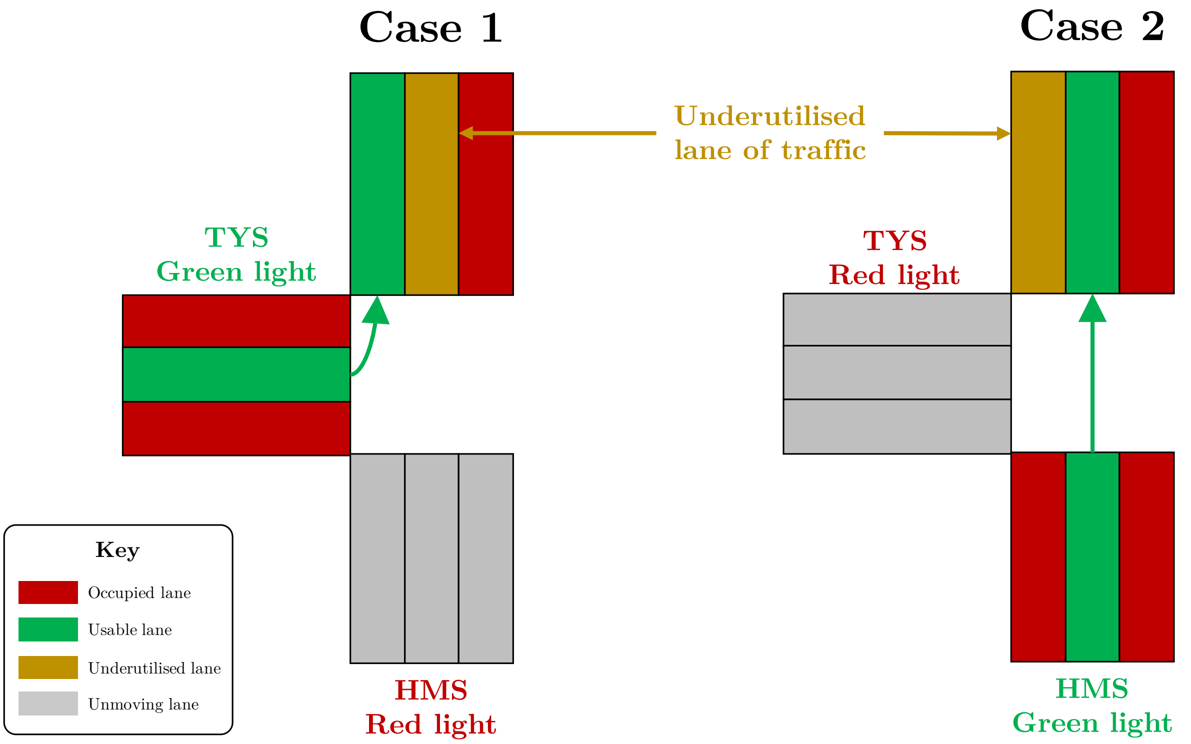


Figure 6.12. Demonstration of how one lane is always underutilised due to the misconfiguration of traffic lights, based on roadside observations in the intersection of TYS and HMS.

As demonstrated above, because of the misconfiguration of traffic light signals, the potential traffic volume at this intersection is reduced by 50%, explaining why both TYS and HMS experience an unusual level of traffic congestion.

Overall, it has been demonstrated that in KT, the overall scarcity of parking spaces and the physical limitations in the road design can cause chronic traffic congestion. This provides additional justifications for drivers to park illegally, further making the argument of parking accessibility being the sole variable to traffic congestion weak.

7 Conclusion

To conclude, by quantifying the parking distribution using the Ga2SFCA method and measuring the severity of traffic congestion with the vehicular speed, it has been found that there is a statistically significant negative correlation between parking accessibility and relative vehicle speed. This is explained by the fact that the overabundance of parking spaces encourages the movement of vehicles towards the parking facility, causing the road to be oversaturated and therefore introducing traffic congestion.

However, while parking accessibility does fundamentally alter the parking location of the driver, it is important to note that parking accessibility is not the only causation of traffic congestion but can also be affected by a multitude of different spatial factors. One of the prominent factors is land use of the area, as it determines the dominant type of activities present. Given that the risk attitude of drivers varies between different types of industries, the willingness to illegally park is directly related to the socioeconomic nature of the activity. Other physical limitations, such as the region-wide insufficiency of parking spaces, poor road designs and the mismanagement of traffic light signals are also observed to alter the driver's normal parking behaviour.

Overall, while the findings of this study can be generalised by that parking accessibility correlates with the severity of traffic congestion, the wide range of other factors that affect traffic congestion is too complicated to be investigated within the scope of the study.

8 Evaluation

Overall, this study was completed successfully with a high degree of accuracy through the use of a sophisticated accessibility index that accounts for both spatial and aspatial interactions, an innovative method of measuring traffic speed using a self-developed web interface and through complex data processing procedures using GIS software and Python.

However, there were several limitations to this study:

8.1 Methodology

Fundamentally, the choice of using 2SFCA as a measure of accessibility may be flawed. Although it has gained much support from geographers, 2SFCA has only been proposed recently in the 2000s (Tao et al., 2020), making results unproven and potentially unreliable. Because the majority of the existing literature used 2SFCA to assess the equity of healthcare and educational services on a nationwide scale where distance-decay effects are significant, it was never observed to be used on such a microscopic street-scale level.

8.2 Choice of the study area

As explored in the analysis, since KT is a predominantly industrial area, many vehicles often do not park at dedicated parking facilities due to the time-sensitive nature of their work. Therefore, this study could be performed in other areas where the land use is less homogenous or industrial, for example, in Mong Kok, where there are many mixed-use commercial-residential buildings (Xue et al., 2001). By changing the study area to areas with a greater variety of land use, it would enable a less biased and in-depth analysis.

8.3 Issues with catchment distance

In this study, the service catchment distance of 972m is used for all vehicles. There are multiple problems with this:

1. Because industrial vehicles are observed to not search or cruise for parking, it is inaccurate to large catchment distances when in reality, it is unlikely to exceed 20m due to the physical limitations of transporting goods.
2. The catchment distance is calculated by the product of average search time and vehicular velocity, which are collected via secondary sources that may be unreliable. Because KT is renowned for its poor traffic performance, the search time and velocity are likely to be much lower than the average speed of HK, hence the accuracy of the catchment distance can be further improved by conducting on-site surveys.
3. Since it has been established that driver behaviour varies largely between different industries, employing the same catchment distance is unreflective of real-world observations. This error could be reduced by using the multi-mode 2SFCA (MMGa2SFCA), which makes catchment distances dependent on the transport mode (Wang et al., 2021):

$$A_i = \sum\nolimits_j \frac{\sum_m S_j f(d_{ij}, d_i)}{\sum_k \sum_m D_k f(d_{jk}, d_j)} \tag{7.1.1.1}$$

   Where m is each transport mode.

8.4 Issues with the measurement of traffic speed

Because traffic congestion is severe in KT, there are frequent lane-switching that confuses the observer on whether the vehicle should be counted. Additionally, because HK is a left-hand drive city, drivers often unload people and goods on the leftmost lane, causing the interruption of traffic flow on the left more significant on the right. Therefore, selecting the leftmost lane for measurement is inconsistent and can lead to errors. This issue can be reduced by measuring all lanes of traffic, and the accuracy of the speed measurement can be further improved by measuring and incorporating into a function suggested by Ye et al. (2006).

8.5 Violations to assumptions

There are several assumptions to the hypothesis that are also violated, specifically:

- The assumption that all parking facilities have the same price. In fact, parking fees play a significant effect in the attractiveness of the facility (Nurul Habib et al., 2012). This can be accounted for by increasing the relative supply (D) when the price is low.
- Based on a survey (Master Alliance Ltd., 2021), 93.3% of respondents in KT agree the root cause of traffic congestion is the insufficiency of parking spaces, therefore the accessibility index A_i should not be expressed in relative terms but scaled accordingly to HK average to accurately determine whether drivers' behaviour.

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10 Appendix

10.1 List of acronyms

HK - Hong Kong
KT - Kwun Tong
QoL - Quality of life
SRCC - Spearman Rank Correlation Coefficient
MGV - Medium Goods Vehicle
KTR - Kwun Tong Road
SYS - Shing Yip Street
HMS - How Ming Street
HYS - Hing Yip Street
HTR - Hung to Road
WYS - Wai Yip Street
HBR - Hoi Bun Road
KYS - King Yip Street
HYR - Hoy Yuen Road
TYS - Tsun Yip Street
CYS - Chong Yip Street

10.2 List of all parking facilities

ID	HK80 Coordinates		Name	GFA	Amount
0	840105.8	819684.9	The Quayside	139837	584
1	840139.2	819610.8	One Bay East	147965	400
2	840306.4	819448.4	NEO	86996	382
3	840441.2	819302.2	MG Tower	71018	309
4	840488.4	819257.4	Seaview Centre	21135	109
5	840492.4	819253.3	China Aerospace Centre	20231	105
6	840636.5	819069.4	D.J. Securities Building	15713	87
7	840830.1	818915.8	Kwun Tong Harbour Plaza	33044	157
8	840833.5	818918.5	Two Harbour Square	67077	293
9	840921	818914.6	Pioneer Place	27317	134
10	841083.4	818907.4	Westley Square	48298	218
11	841077.8	818913.1	ELI PARKING @ Lemmi Centre	21194	109
12	841113.2	818871.4	Benson Tower	15299	86
13	841154.5	818821.1	Kras Asia Industrial Building	11992	17
14	841198.2	818768.1	ELI PARKING @ Ray Centre	6326	36
15	841188.2	818780	EGL Tower	45323	206
16	841029.3	818651.3	Lu Plaza	62101	273
17	841432.8	818956.3	Lever Tech Centre	6437	36
18	841428.3	818961.8	Sunbeam Centre	61062	269
19	841416	818976.4	Shing Yip Industrial Building	39816	58
20	841610.5	818953.5	Cha Kwo Ling Road		200

21	841244.7	818920.6	Chung Mei Centre	27394	134
22	841207	818966.1	Camel Paint Building Block 3/Camel	47717	215
23	841130.8	819004.5	Glenplas Factory Building	13243	19
24	841087.5	818968.5	Hewlett Centre	52506	235
25	841190.7	819054.1	Aitken Vanson Centre Car Park	22909	116
26	841137.4	819010.1	Hoi Leun Industrial Centre	125230	185
27	841001.3	819001.9	Pang Kwong Building	5685	32
28	840986	819021.2	Nanyang Plaza	60201	265
29	840959.8	819130.8	COS Centre	91494	390
30	841025.8	819187.9	Capital Trade Centre	12047	68
31	841049.3	819208.3	South Asia Commercial Building	13974	79
32	841168.3	819164.6	Speedy Industrial Building	15104	22
33	841181.1	819149.1	Entreport Centre	14229	81
34	841144.3	819194.4	Futura Plaza	35762	63
35	841131	819210.3	Wing Cheung Industrial Building	9023	13
36	841111.3	819278.2	Fully Industrial Building	6877	10
37	841228.9	819085.2	Camel Paint Building Blocks 1 & 2/C	17518	95
38	841308.8	819103.9	Yen Sheng Centre	23477	118
39	841329.3	819079.4	Prosperity Place Car Park	18068	97
40	841335.2	819072.5	TG Place	47011	213
41	841312.9	819099.3	Kwun Tong Plaza	29518	143
42	841339.2	819067.9	Legend Tower	69658	303
43	841242.5	819304.7	apm	321206	268
44	841185.6	819326.3	One Pacific Centre	39341	182
45	841169	819335.4	Kwun Tong View	16511	91
46	840839.7	819035.7	Assun Pacific Centre	7941	45
47	840748.4	819101	Sitoy Tower	2936	16
48	840510.2	819360	China Trade Centre	11557	66
49	840493.8	819392.1	Pan Asia Centre	6846	39
50	840479.6	819482.4	Draco Industrial Building	6224	9
51	840261.4	819695.9	Bunhoi Group Centre	2446	13
52	840405.5	819502.6	International Trade Tower	96614	411
53	840548.2	819467.7	NO. 1 Hung To Road	94070	401
54	840567.5	819448.7	Kinox Centre	18427	98
55	840642.7	819459.4	Prosperity Center Car Park	37339	174
56	840696.3	819470.8	Millennium City 2 & 3	43967	200
57	840745.9	819420.2	Montery Plaza	16266	90
58	840643.2	819379.7	Fullerton Centre	15228	85
59	840660.4	819362.6	Infotech Centre	15696	87
60	840686.9	819337.6	Remington Centre	15414	86
61	840662.3	819351.1	Westin Centre	29984	144
62	840743.6	819277.3	Billion Trade Centre	15653	87
63	840809	819212.9	Wah Hung Centre	10822	61
64	840871.5	819151.3	Paul Y. Centre (Wilson Parking)	21524	111
65	840829.1	819361	Millennium City 1 (Wilson Parking)	188966	780
66	840907.5	819328.8	Millennium City 6 (Wilson Parking)	93047	397

67	840945.6	819313.2	Landmark East Carpark	32673	454
68	841035.9	819277.5	How Ming Factory Building	22141	32
69	841293	818804.9	King Palace Plaza	42610	196
70	841032.8	818786.4	Manulife Financial Centre	106275	451

10.3 List of all survey points

ID	HK80 coordinates		accessibility	occupancy	speed	Rank(x)	Rank(y)	d^2
22	841212.2	819072.1	0.051517	0.5039	2075.023	11	26	225
49	841110.5	818988.4	0.041186	0.454513	1690.971	26	22	16
105	840622.7	819555.5	0.030712	0.226691	3214.286	41	34	49
138	841208.6	819320.3	0.030816	0.154635	5147.653	40	49	81
159	841000.9	818805.6	0.031939	0.379078	2842.704	39	32	49
212	840882.1	819456.5	0.002788	0.212874	5545.96	61	52	81
239	840756.7	819506.6	0.008991	0.166552	7729.93	55	58	9
290	840528	819534.9	0.046441	0.276629	1376.657	18	20	4
394	840863	818983	0.022542	0.11112	10252.11	48	62	196
421	841388.4	819215.5	0.044698	0.365094	3436.352	20	40	400
433	841259.2	819110.3	0.064662	0.652188	1280.982	3	18	225
458	841312.1	819269.5	0.025613	0.139673	6188.816	46	55	81
499	841048.8	819391.1	0.037419	0.355506	2111.555	31	27	16
589	840558.1	819329.3	0.052153	0.293076	4464.113	10	46	1296
632	840553.4	819319.6	0.020225	0.136124	7596.055	50	57	49
841	840504.4	819601.4	0.008921	0.105949	5250.745	56	51	25
1015	840711	819149.7	0.004653	0.335756	3070.515	58	33	625
1075	840746.7	819123.6	0.026397	0.607991	1005.069	45	12	1089
1107	841591.6	818916	0.048425	0.077625	5236.14	16	50	1156
1210	841464.2	819169.8	0.033542	0.536158	1047.127	36	14	484
1261	840265	819606.2	0.01807	0.135114	8166.486	51	60	81
1283	840854.7	818978.3	0	0.257666	3729.217	62	42	400
1336	840605.5	819096.2	0.011627	0.084561	7927.021	53	59	36
1375	840608.7	819100.7	0.011888	0.077905	6009.502	52	54	4
1495	841330.6	819171.1	0.044311	0.514281	1376.628	23	19	16
1700	840202.5	819541	0.021128	0.056253	6823.836	49	56	49
1735	840323.2	819414.9	0.032519	0.426262	587.9425	37	7	900
1754	840590.9	819210.9	0.009739	0.276859	650.9632	54	9	2025
1804	840871.4	819061.8	0.042827	0.460813	1119.954	25	15	100
1823	840945.5	819119.9	0.028857	0.589871	569.9069	44	6	1444
1850	841048	819207.3	0.037533	0.885911	270.029	30	1	841
1868	840769.8	818974.7	0.032177	0.757622	474.4625	38	5	1089
1899	841087.5	818705	0.044323	0.186087	4926.575	22	48	676
1904	840826.5	819362.4	0.048811	0.285913	2166.741	14	28	196
1938	841372	819027.3	0.043347	0.371	1572.529	24	21	9
2004	841380.2	818861.8	0.058276	0.322568	2792.391	6	31	625
2041	841283.3	818783.1	0.056065	0.308125	2649.118	7	30	529
2062	841186	818991.8	0.034654	0.298795	986.4095	34	11	529

2091	841279.3	818880.8	0.044725	0.209111	1946.565	19	24	25
2131	840845.7	818926	0.022618	0.229694	3340.68	47	35	144
2175	840767.1	819253.6	0.029446	0.072644	5615.709	43	53	100
2201	840859.8	819162.5	0.040608	0.066235	3883.876	27	44	289
2252	840973.1	819039.1	0.035368	0.409902	963.6756	33	10	529
2308	840994	819293.4	0.050663	0.242148	2020.036	13	25	144
2328	840871.2	819343.9	0.055672	0.236442	3341.255	8	36	784
2354	841118.1	819223.5	0.038729	0.798196	345.3597	29	3	676
2373	840749.9	819345.3	0.048599	0.084254	1132.788	15	16	1
2393	840669.4	819277.7	0.067754	0.445032	1172.691	2	17	225
2417	841193	819134.1	0.029731	0.585129	592.6609	42	8	1156
2437	841093.6	818892.8	0.036918	0.058924	3816.996	32	43	121
2461	841170.2	818800.4	0.047556	0.085252	3373.287	17	37	400
2481	840744.4	819420.1	0.055668	0.320124	3435.255	9	39	900
2491	840708.8	819455.2	0.061829	0.102435	4630.672	4	47	1849
2513	840624.9	819441.3	0.073583	0.15409	3715.969	1	41	1600
2549	840692.1	819332.6	0.061765	0.77982	320.8978	5	2	9
2567	840438.6	819536.1	0.004554	0.144588	1715.141	59	23	1296
2595	840101.5	819673.7	0.044596	0.607767	1006.783	21	13	64
2643	840197.4	819536.3	0.040591	0.092324	9635.908	28	61	1089
2665	840411.6	819323.7	0.00381	0.301607	2387.242	60	29	961
2694	840515.1	819222.2	0.008178	0.081132	4287.474	57	45	144
2716	840318.1	819409.4	0.033871	0.212116	3389.777	35	38	9
2979	840644.8	819368.4	0.050813	0.675395	459.0035	12	4	64
							$\sum d^2$	**28284**

10.4 Code used for calculating 2SFCA

Filename: sfca.py

```
from db import common
import pandas as pd

from rich import print, inspect
from rich.progress import track

with common.Session(common.engine) as session:
    samples = session.query(common.Sample).all()
    carparks = session.query(common.Carpark).all()
    population = session.query(common.Population).all()

survey_ids = ('632', '1804', '105', '2354', '2175', '22', '1700', '1283', '2308', '2252', '239', '2328',
'1823', '841', '433', '2491', '1495', '458', '1075', '2481', '2979', '2062', '1735', '2567', '138',
'2373', '2201', '2643', '159', '290', '1336', '212', '2041', '2004', '394', '2665', '2694', '1107',
'2417', '589', '1899', '1850', '2549', '2091', '2513', '1904', '1868', '1261', '1938', '1754', '2716',
'2437', '1210', '49', '2461', '499', '1015', '2131', '2393', '2595', '1375', '421')
carpark_catchment_distance = 972
population_catchment_distance = 181.83

sfca = common.SFCA(samples=samples, carparks=carparks, population=population,
carpark_catchment_distance=carpark_catchment_distance,
population_catchment_distance=population_catchment_distance).calculate()
df = pd.DataFrame([sample.genRow() for sample in sfca.samples], columns=common.Sample.__csvHeaders__)
```

```
df.to_csv('out/sample.csv', index=False)

sfca = common.SFCA(samples=[s for s in samples if s.sample_id in survey_ids], carparks=carparks,
population=population, carpark_catchment_distance=carpark_catchment_distance,
population_catchment_distance=population_catchment_distance).calculate()
df = pd.DataFrame([sample.genRow() for sample in sfca.samples], columns=common.Sample.__csvHeaders__)
df.to_csv('out/sample_survey.csv', index=False)
```

Filename: survey.py

```
import os
from rich import print, inspect
import pandas as pd

class Survey:
    def __init__(self, surveyid, data):
        self.surveyid = surveyid
        self.data = data

        self.total_occupied_duration = sum(self.data.iloc[i+1].t - self.data.iloc[i].t for i in
range(len(self.data)-1) if self.data.iloc[i].state == 1 and self.data.iloc[i+1].state == 0)
        self.total_duration = self.data.iloc[-1].t
        self.vehicle_count = sum(1 for d in self.data.itertuples() if d.state == 1)

        self.occupancy = self.total_occupied_duration / self.total_duration
        self.flow = self.vehicle_count / (self.total_duration / 3600) # veh/hr
        self.relativeSpeed = self.flow / self.occupancy

sfca_df = pd.read_csv('out/sample_survey.csv', index_col='sample_id')

surveys = []
for filename in os.listdir('survey/raw/json'):
    survey_processed = Survey(filename.split('.')[0], pd.read_json(os.path.join('survey/raw/json',
filename)))
    survey_sfca = sfca_df.loc[int(survey_processed.surveyid)]
    surveys.append([survey_processed.surveyid] + survey_sfca.values.tolist() +
[survey_processed.occupancy, survey_processed.flow, survey_processed.relativeSpeed])

df = pd.DataFrame(surveys, columns=['id', *sfca_df, 'occupancy', 'flow', 'relativeSpeed'])
df.to_csv('out/processed_survey.csv', index=False)
```

Filename: db/common.py

```
import math
from pyproj import Transformer, Proj
from rich import print, inspect
from rich.progress import Progress
from .models import *

from sqlalchemy.sql import select

hk80_to_wgs84 = Transformer.from_crs("epsg:2326", "epsg:4326").transform
wgs84_to_hk80 = Transformer.from_crs("epsg:4326", "epsg:2326").transform
hk80 = Proj('epsg:2326')
wgs84 = Proj('epsg:4326')

class Coordinate:
    def __init__(self, lat=None, lon=None, x=None, y=None, autoconvert=True):
        self.lat = float(lat) if lat else None
        self.lon = float(lon) if lon else None
        self.x = float(x) if x else None
        self.y = float(y) if y else None

        if autoconvert:
```

```
            if self.x is None and self.y is None:
                self.getHK80()
            if self.lat is None and self.lon is None:
                self.getWGS84()

    def getWGS84(self):
        if self.x and self.y:
            self.lat, self.lon = hk80_to_wgs84(self.y, self.x)

    def getHK80(self):
        if self.lat and self.lon:
            self.y, self.x = wgs84_to_hk80(self.lat, self.lon)

class SFCA:
    def __init__(self, samples, carparks, population, carpark_catchment_distance,
population_catchment_distance):
        self.samples = samples
        self.carparks = carparks
        self.population = population
        self.carpark_catchment_distance = carpark_catchment_distance
        self.population_catchment_distance = population_catchment_distance

    def decayCarpark(self, distance):
        if distance < self.carpark_catchment_distance:
            return (math.exp(-0.5*(math.pow((distance/self.carpark_catchment_distance), 2))) -
math.exp(-0.5)) / (1-math.exp(-0.5))
        return 0

    def decayPopulation(self, distance):
        if distance < self.population_catchment_distance:
            return (math.exp(-0.5*(math.pow((distance/self.population_catchment_distance), 2))) -
math.exp(-0.5)) / (1-math.exp(-0.5))
        return 0

    def calculate(self):
        with Session(engine) as session, Progress() as progress:
            sfcatask = progress.add_task("[yellow]Running SFCA...", total=len(self.samples))
            for sample in self.samples:
                try:
                    sample.accessibility = 0
                    for carpark in self.carparks:
                        d =
session.execute(select(CarparkMatrix.total_cost).where((CarparkMatrix.origin_id == sample.sample_id) &
(CarparkMatrix.destination_id == carpark.carpark_id))).fetchone()[0]
                        if d is None: continue
                        supply = carpark.amount * self.decayCarpark(d)

                        demand = 0
                        for gfa, distance in session.execute(select(Population.gfa,
PopulationMatrix.total_cost).where(PopulationMatrix.origin_id == carpark.carpark_id).join(Population,
PopulationMatrix.destination_id == Population.building_id)):
                            if distance is None: continue
                            demand += gfa * self.decayPopulation(distance)

                        if demand == 0: continue
                        sample.accessibility += supply / demand
                except Exception:
                    pass
                finally:
                    progress.update(sfcatask, advance=1)

        return self
```

Filename: models.py

```
from sqlalchemy import create_engine
from sqlalchemy import Column, String, Integer, Float
from sqlalchemy.ext.declarative import declarative_base
from sqlalchemy.orm import Session
import csv
from rich import print, inspect

Base = declarative_base()
engine = create_engine('sqlite:///db/data.db', echo=False)

class Sample(Base):
    __tablename__ = "samples"
    __csvHeaders__ = ("sample_id", 'x', 'y', 'routeid', 'distance', "accessibility")

    sample_id = Column('sample_id', String, primary_key=True, index=True)
    x = Column('x', Float)
    y = Column('y', Float)
    routeid = Column('routeid', Integer)
    distance = Column('distance', Integer)
    accessibility = Column('accessibility', Float)

    def genRow(self):
        return (self.sample_id, self.x, self.y, self.routeid, self.distance, self.accessibility)

class Population(Base):
    __tablename__ = "population"

    building_id = Column('building_id', String, primary_key=True, index=True)
    typeofbuilding = Column('typeofbuilding', String)
    height = Column('height', Float)
    floor = Column('floor', Integer)
    gfa = Column('gfa', Integer)
    x = Column('x', Float)
    y = Column('y', Float)

    def genRow(self):
        return (self.building_id, self.typeofbuilding, self.height, self.floor, self.gfa, self.x,
self.y)

class PopulationMatrix(Base):
    __tablename__ = "populationMatrix"

    pk = Column('pk', Integer, primary_key=True, autoincrement=True)
    origin_id = Column('origin_id', String, index=True)
    destination_id = Column('destination_id', String, index=True)
    entry_cost = Column('entry_cost', Float)
    network_cost = Column('network_cost', Float)
    exit_cost = Column('exit_cost', Float)
    total_cost = Column('total_cost', Float)

    def genRow(self):
        return (self.origin_id, self.destination_id, self.entry_cost, self.network_cost, self.exit_cost,
self.total_cost)

class Carpark(Base):
    __tablename__ = "carpark"

    carpark_id = Column('carpark_id', String, primary_key=True, index=True)
    description = Column('description', String)
    source = Column('source', String)
    gfa = Column('gfa', Integer)
    type = Column('type', String)
    amount = Column('amount', Integer)
    x = Column('x', Float)
    y = Column('y', Float)
```

```
    def genRow(self):
        return (self.carpark_id, self.description, self.source, self.gfa, self.type, self.amount,
self.x, self.y)

class CarparkMatrix(Base):
    __tablename__ = "carparkMatrix"

    pk = Column('pk', Integer, primary_key=True, autoincrement=True)
    origin_id = Column('origin_id', String, index=True)
    destination_id = Column('destination_id', String, index=True)
    entry_cost = Column('entry_cost', Float)
    network_cost = Column('network_cost', Float)
    exit_cost = Column('exit_cost', Float)
    total_cost = Column('total_cost', Float)

    def genRow(self):
        return (self.origin_id, self.destination_id, self.entry_cost, self.network_cost, self.exit_cost,
self.total_cost)

Base.metadata.create_all(engine)

# automatically insert data if not present.
with Session(engine) as session:
    if not session.query(Sample).count():
        print("Inserting sample...")
        with open(f'samples.csv', 'r', encoding='utf-8-sig', newline='') as f:
            data = list(csv.reader(f))[1:]
            session.bulk_save_objects([Sample(**{
                "sample_id": d[0],
                "x": d[1],
                "y": d[2],
                "routeid": d[3],
                "distance": d[4],
            }) for d in data])

    if not session.query(Population).count():
        print("Inserting population...")
        with open(f'populations.csv', 'r', encoding='utf-8-sig', newline='') as f:
            data = list(csv.reader(f))[1:]
            session.bulk_save_objects([Population(**{
                "building_id": d[0],
                "typeofbuilding": d[2],
                "height": float(d[3]) if d[3] else 0,
                "floor": int(d[4]) if d[4] else 0,
                "gfa": int(d[5]) if d[5] else 0,
                "x": float(d[6]),
                "y": float(d[7]),
            }) for d in data])

    if not session.query(PopulationMatrix).count():
        print("Inserting population matrix...")
        with open(f'population_matrix.csv', 'r', encoding='utf-8-sig', newline='') as f:
            data = list(csv.reader(f))[1:]
            session.bulk_save_objects([PopulationMatrix(**{
                "origin_id": d[0],
                "destination_id": d[1],
                "entry_cost": float(d[2]) if d[2] else None,
                "network_cost": float(d[3]) if d[2] else None,
                "exit_cost": float(d[4]) if d[2] else None,
                "total_cost": float(d[5]) if d[2] else None,
            }) for d in data])

    if not session.query(Carpark).count():
        print("Inserting carpark...")
```

```
        with open(f'carparks.csv', 'r', encoding='utf-8-sig', newline='') as f:
            data = list(csv.reader(f))[1:]
            session.bulk_save_objects([Carpark(**{
                "carpark_id": d[0],
                "description": d[1],
                "source": d[2],
                "gfa": int(d[3]) if d[3] else 0,
                "type": d[4],
                "amount": int(d[5]) if d[4] else 0,
                "x": float(d[6]),
                "y": float(d[7]),
            }) for d in data])

    if not session.query(CarparkMatrix).count():
        print("Inserting car parks matrix...")
        with open(f'carpark_matrix.csv', 'r', encoding='utf-8-sig', newline='') as f:
            data = list(csv.reader(f))[1:]
            session.bulk_save_objects([CarparkMatrix(**{
                "origin_id": d[0],
                "destination_id": d[1],
                "entry_cost": float(d[2]) if d[2] else None,
                "network_cost": float(d[3]) if d[2] else None,
                "exit_cost": float(d[4]) if d[2] else None,
                "total_cost": float(d[5]) if d[2] else None,
            }) for d in data])

    session.commit()
```