To what extent does the distribution of parking facilities interplay with the local traffic in Kwun Tong, Hong Kong?

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

Personal code: [redacted]

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1.1 Word Count Breakdown

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1.2 List of figures and maps

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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).

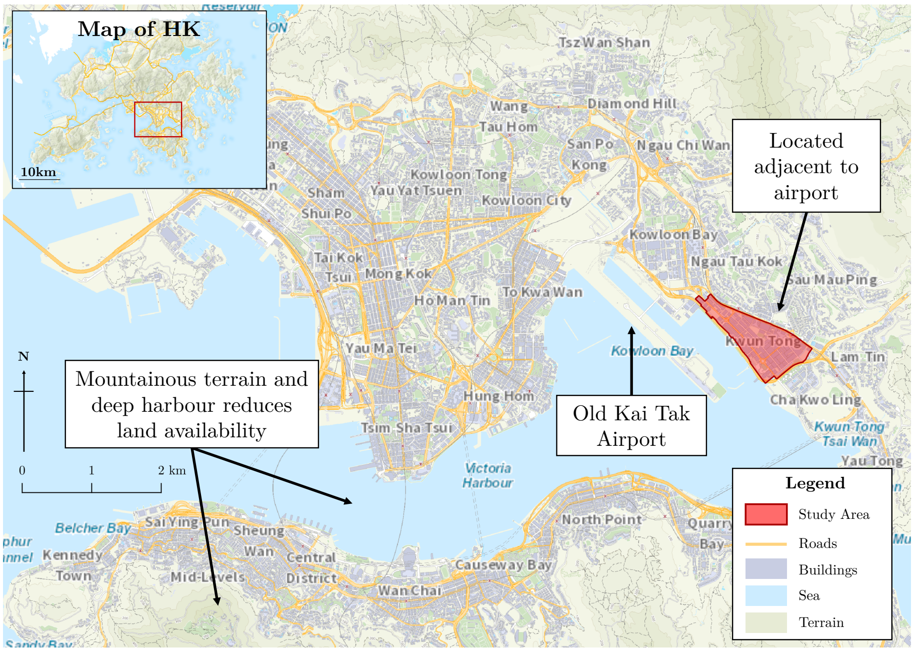
It has historically been trivial to quantify traffic congestion (Aftabuzzaman, 2007). One of the methods developed is the Roadway Congestion Index (RCI), the ratio between the mean time delayed and the theoretical free-flow travel time (Schrank et al., 1994). Although the measure is widely implemented 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

Commented [AC3]: Remove? Extra detail that is not developed 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).

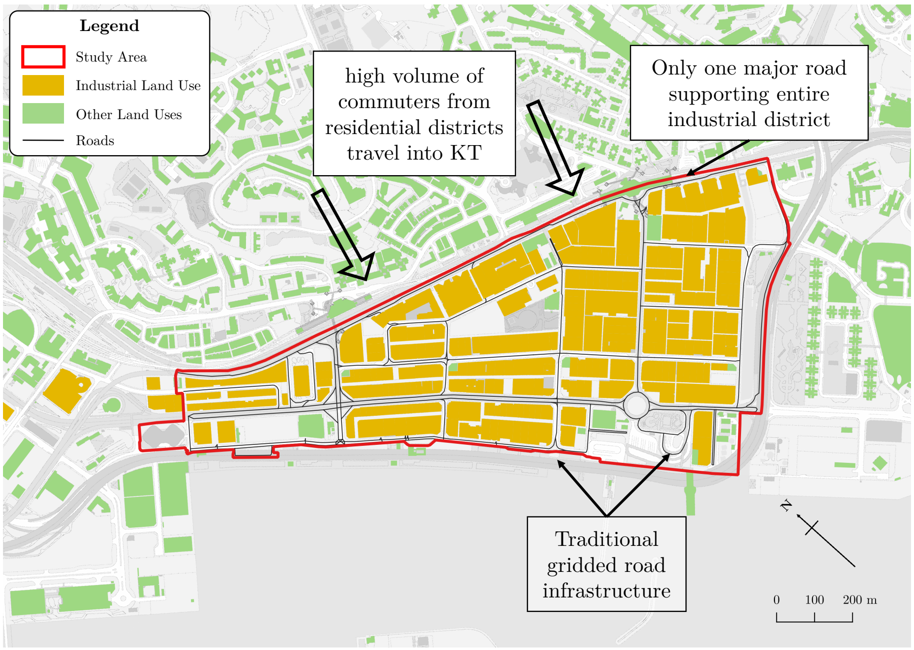
3 Geographical Context



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, 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 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

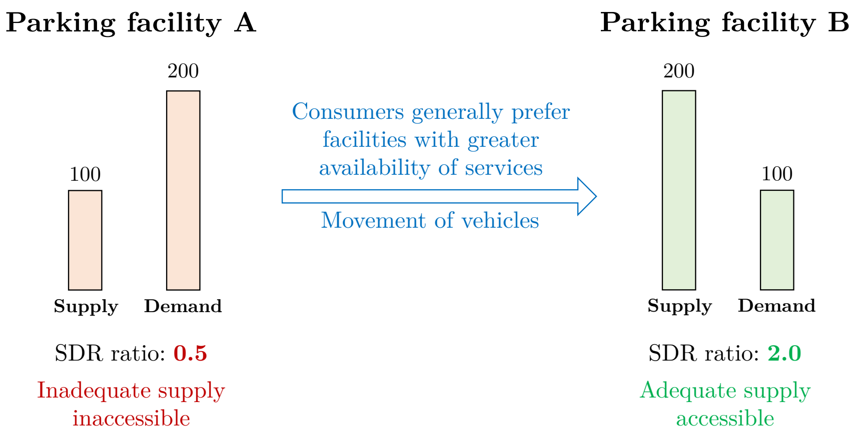


Figure 1. Demonstration of the movement of vehicles to areas with greater parking accessibility.

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 an adequate supply of parking facilities can alleviate traffic congestion, researchers have found that 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 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 costs at the expense of losing the opportunity to park, therefore reducing cruising and leading to smoother traffic (Shoup, 2006).

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The following set of hypotheses will be tested:

Null Hypothesis (H_0)	There is no correlation between the relative magnitude of traffic congestion and the accessibility to parking spaces.
Alternate Hypothesis (H_1)	There is a correlation between the relative magnitude of traffic congestion and accessibility to parking spaces.

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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).

Commented [AC6]: Add flowchart!

[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:

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

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 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:

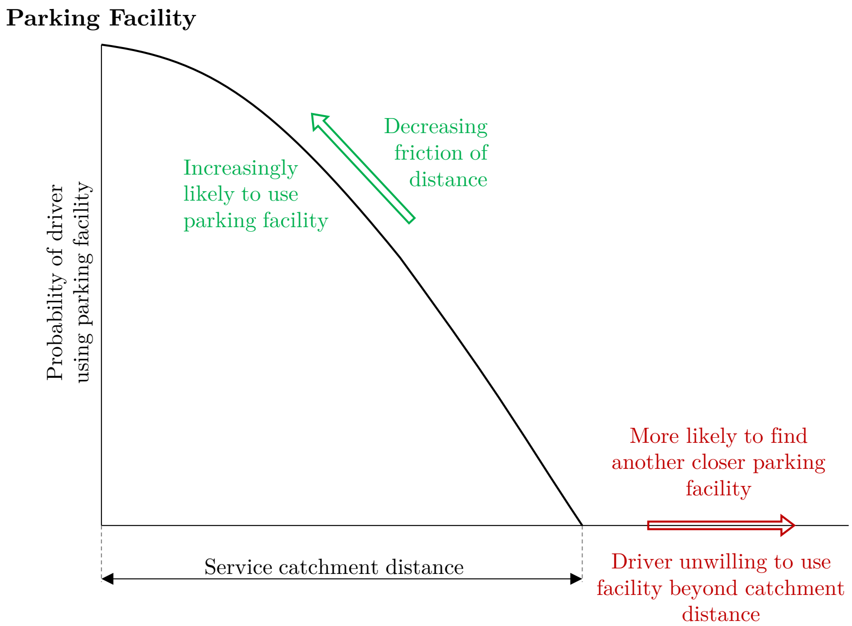


Figure 3. Demonstration of the distance-decay effects on the supply of parking facilities.

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 by:

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

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 to the demand:

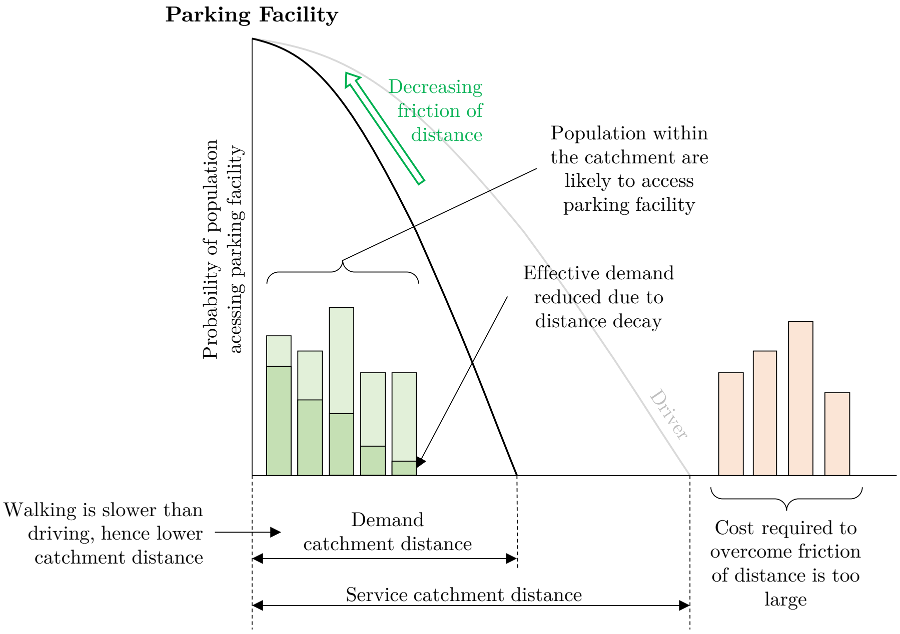


Figure 4. Demonstration of the distance-decay effects on the demand of demand nodes.

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

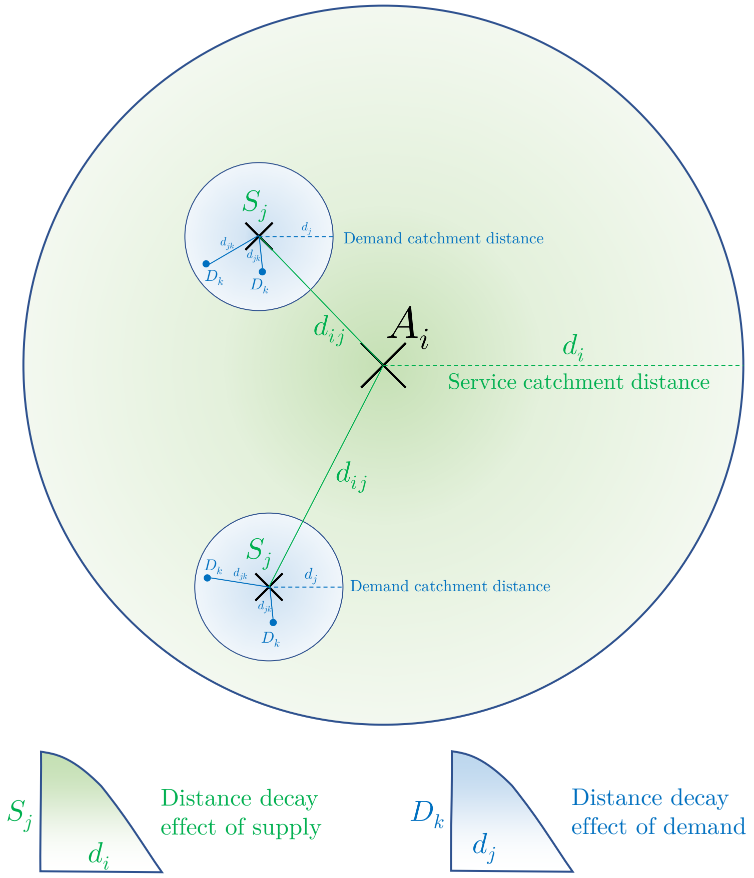
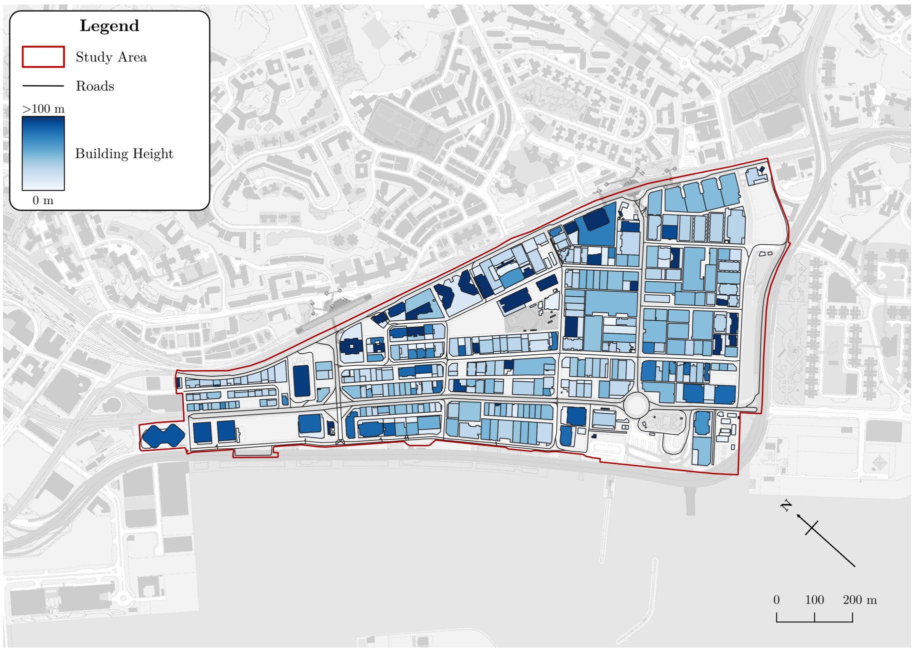


Figure 5. Visual representation of the Ga2SFCA method.

5.1.2 Quantification of demand

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

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

Since the demand is closely correlated to the gross floor area (GFA) of a building, the relative demand is:

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

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)

[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 Ordanace Datum similar to "metres above sea level" (AMSL)

5.1.3 Quantification of supply

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

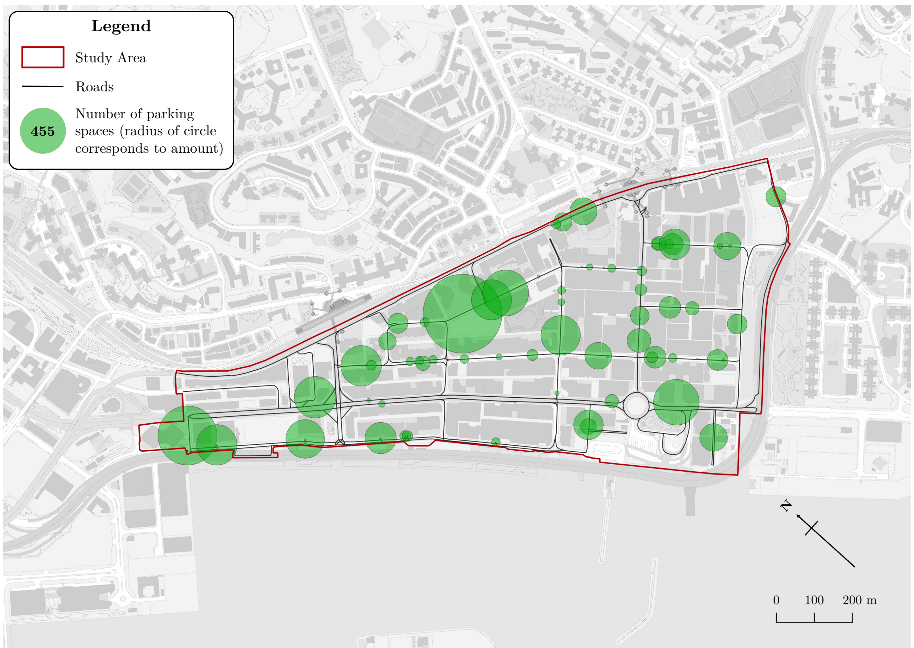
Since the exact number of parking spaces is not publicly available, the supply (S_j) is often estimated using parking standards which are a set of specifications newly constructed buildings must follow (Wang and Liu, 2014). According to the HK Planning Standards and Guidelines (HKPSG), the recommended 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)



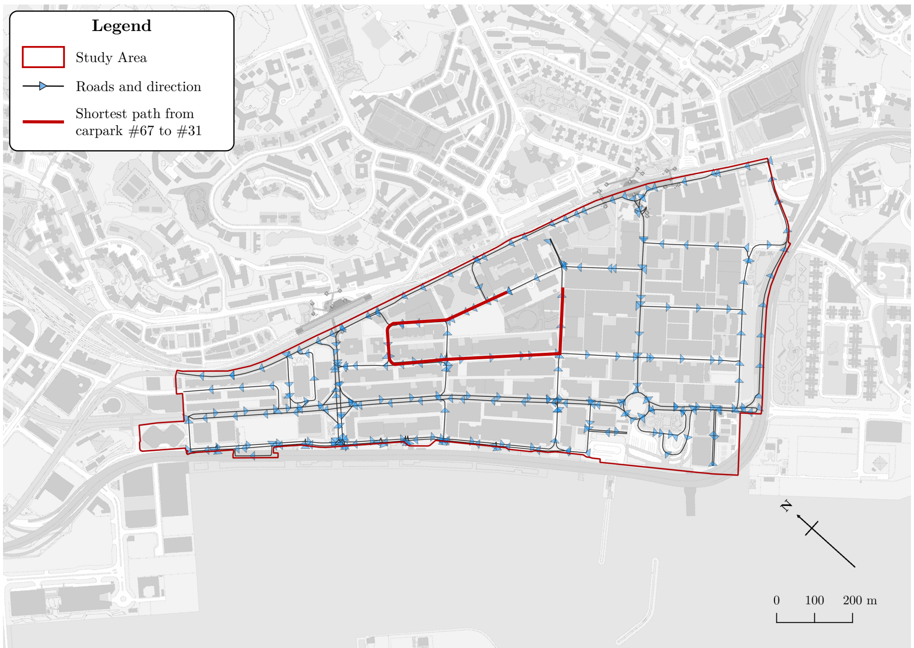
Map 4. Distribution of parking spaces and their amounts within the study area. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

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. 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

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

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 1-2 times. The following constraints are set to maximise data accuracy:

- should be as evenly distributed as possible
- should not be located at/within 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.

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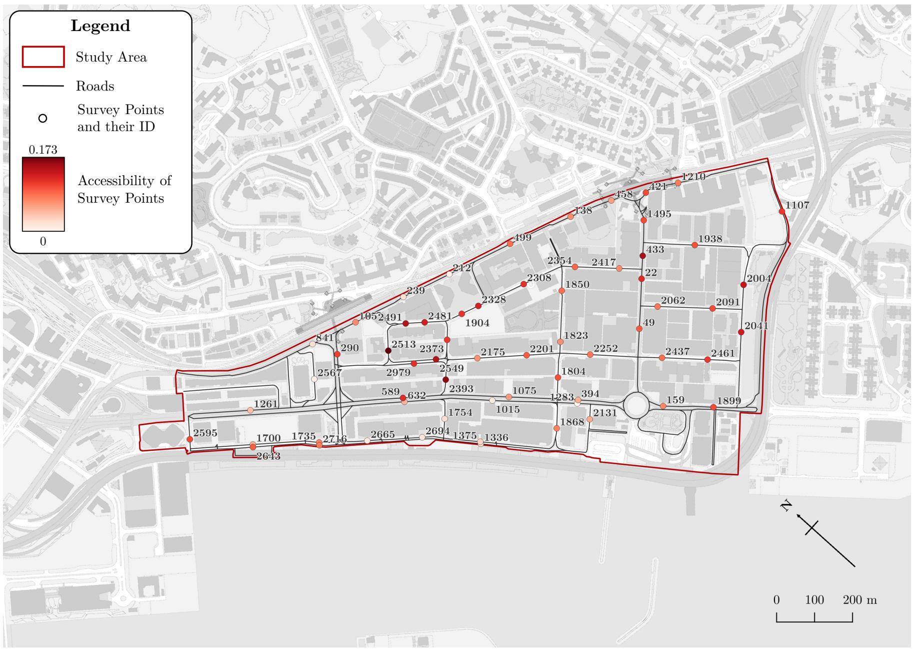


Map 6. The distribution of selected sample points and their accessibility index A_i. (Hong Kong Geodata Store, 2021; Lands Department, 2021)

5.2 Traffic congestion

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).

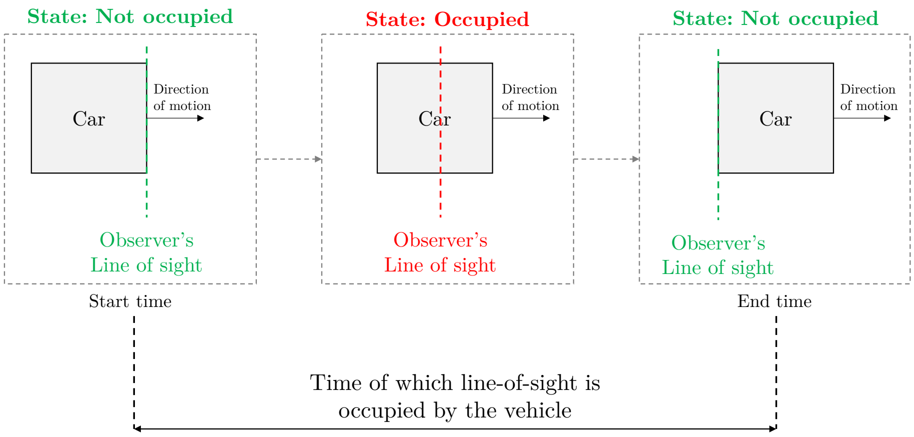


Figure 6. Visual representation of how time-occupancy is calculated.

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:

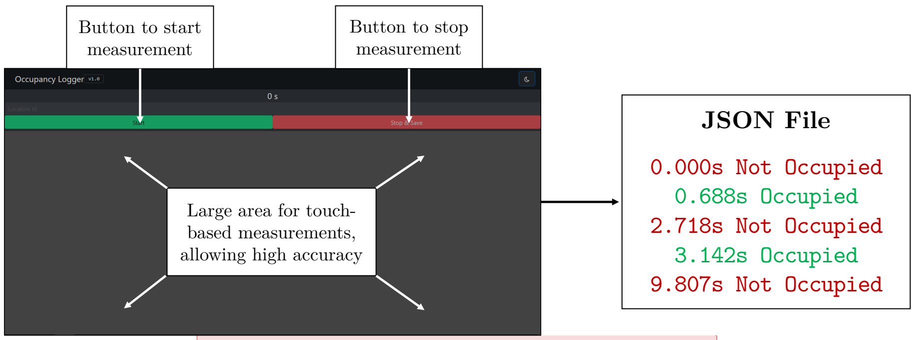


Figure 7. The interface of the logging tool and its output.

Commented [AC8]: Mention instrumental uncertainty of 1ms

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 7[9].

[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

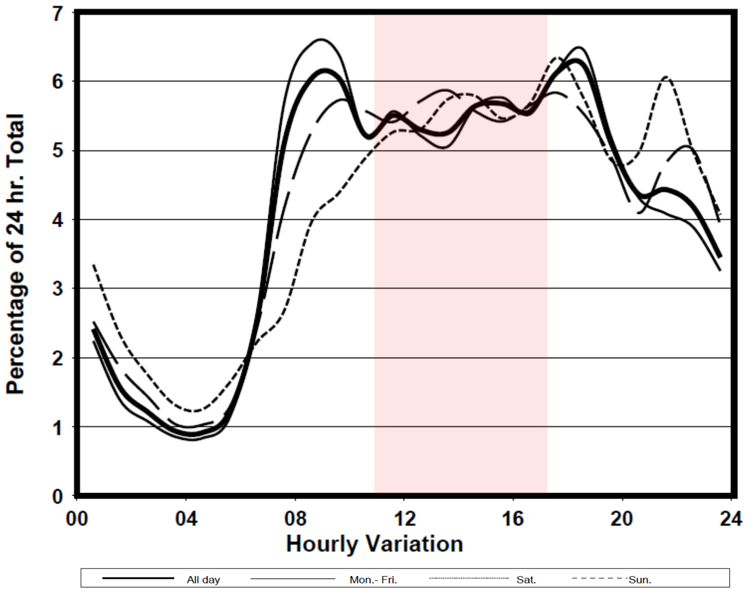


Figure 8. Graph of daily and weekly traffic changes at Station #3012 (Transport Department, 2021).

Commented [AC9]: Add map to show geographical location!

To reduce data fluctuations, surveying shall be performed from 10:00-16:00 because the traffic flow is rather stable, has a sufficiently large volume, and is the time when industrial 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.

Commented [AC10]: Move explanation to graph if time allows

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** $\boldsymbol{x}$, $r(x)$	**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, Σd^2	43.5

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

$$\text{Perfect negative correlation} \quad -1 \longleftarrow R \longrightarrow 1 \quad \text{Perfect positive correlation}$$

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 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 one-tailed p-value:

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

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

Commented [AC11]: Use graph from IA to show pdf function and emphasise on 95% confidence level.

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

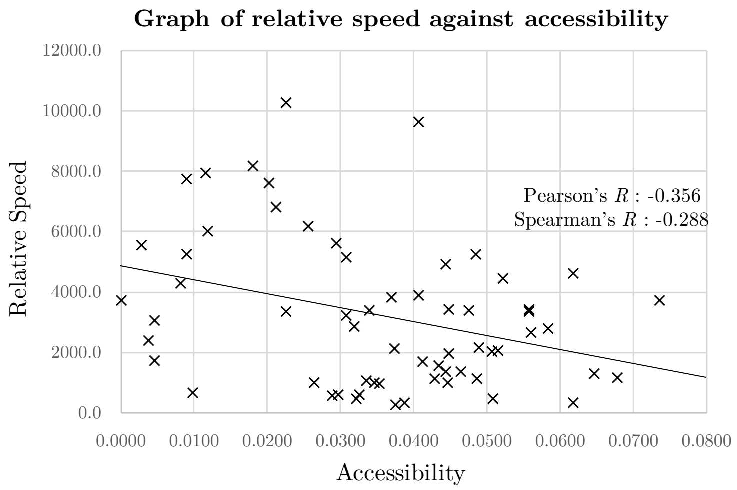


Figure 6.1. A scatter graph showing the relationship between relative speed against accessibility.

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	0.0116
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.

Commented [AC12]: Bold to emphasise findings?

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).

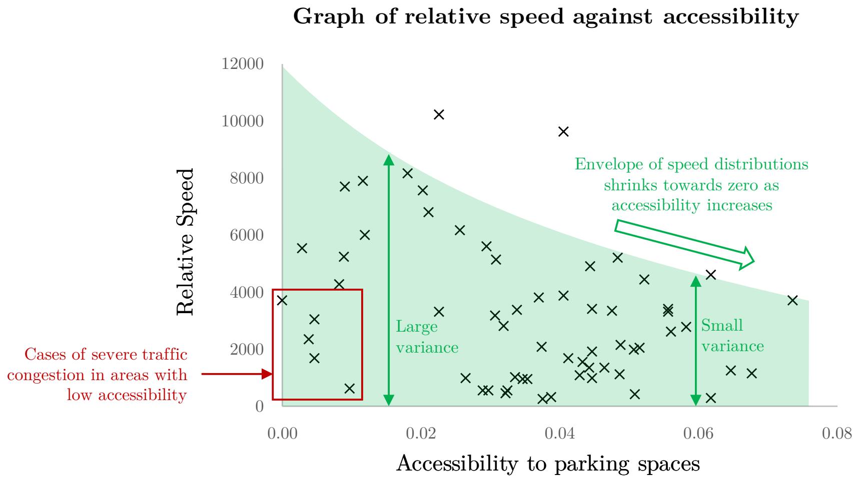


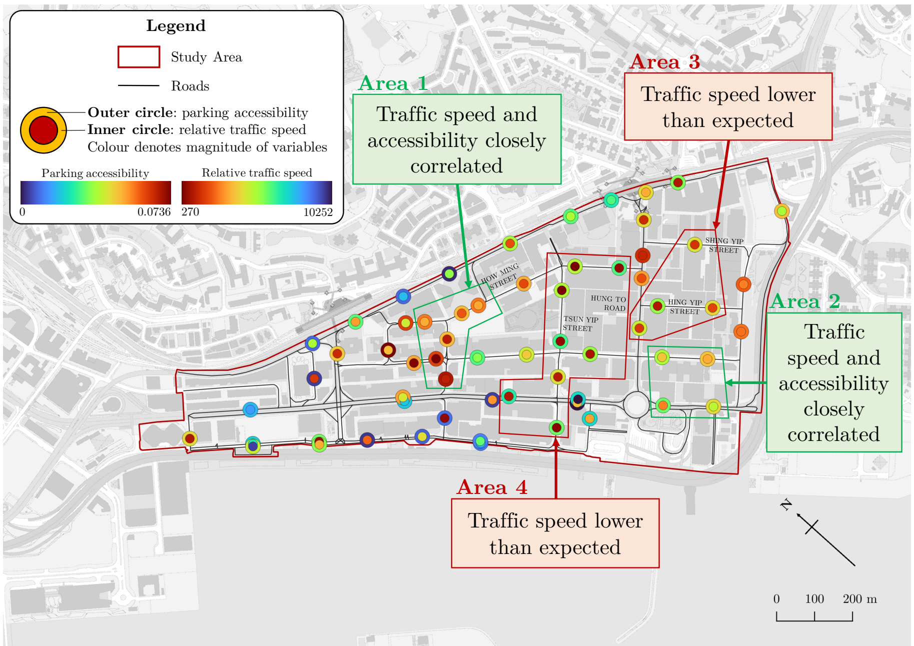
Figure 6.2. Demonstration of how heteroscedasticity can contradict the acceptance of H_1.

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.

Commented [AC13]: Add table to show Type I/II errors.

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 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)

The 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.

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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.

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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.

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6.2.1 Role of land use in traffic congestion

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

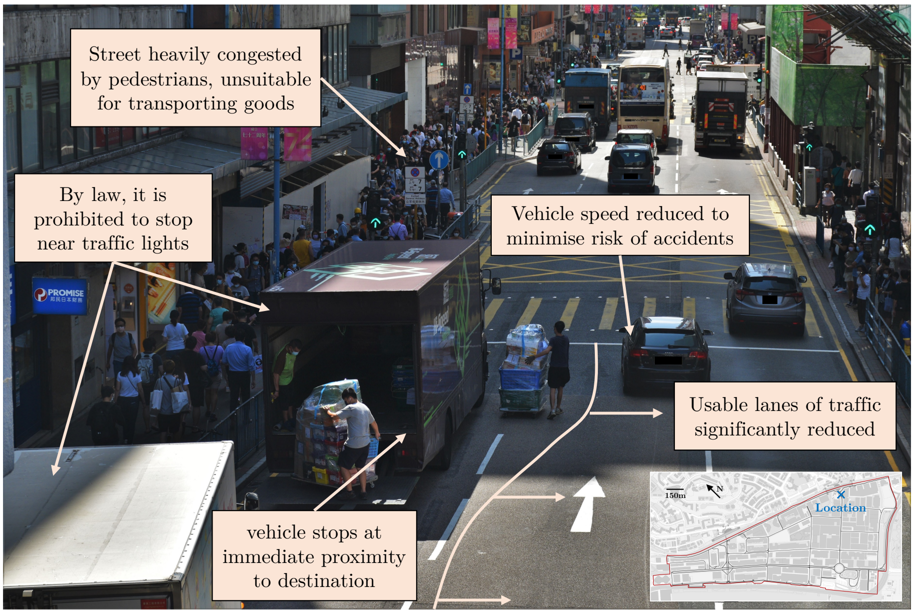

Figure 6.3. Demonstration of industrial vehicles obstructing traffic flow. (841349,819187$^{\text{EPSG:2326}}$)

This behaviour can be attributed by 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 take in account of parking accessibility when unloading goods is invalid.

In addition, the result of unloading goods in the midst of 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 causes 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:

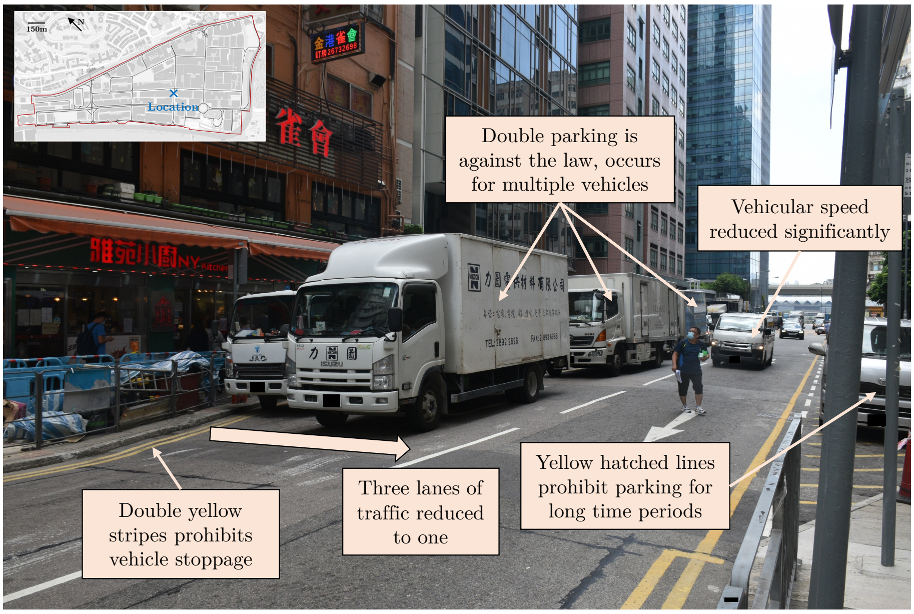

Figure 6.4. Photo of MGVs violating multiple parking restrictions. (*"Cap 374C"*, 2021; 840899,819090$^{\mathrm{EPSG:2326}}$)

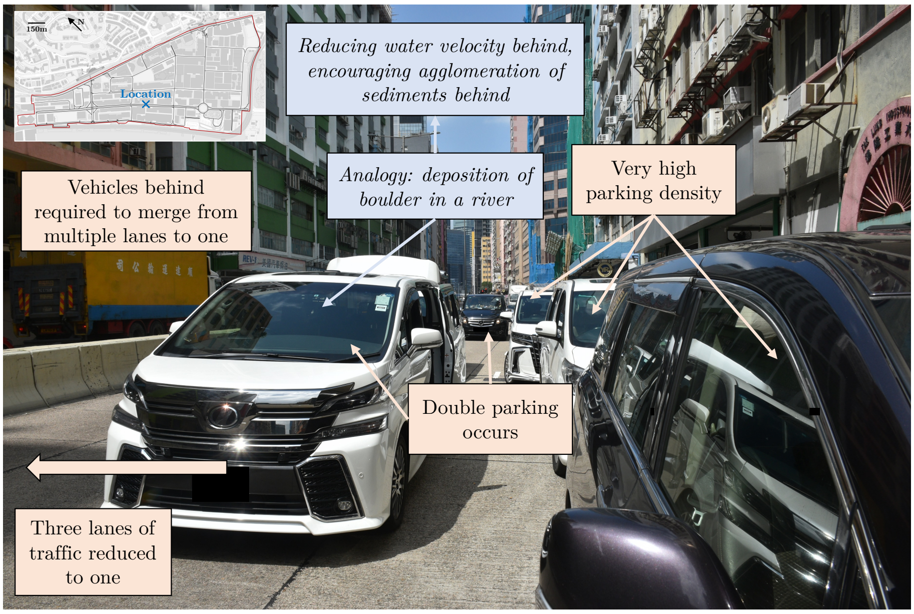

Figure 6.5. Demonstration of how double parking can encourage further double parking and worsen traffic congestion. (*"Cap 374C"*, 2021; 840727,819155$^{\mathrm{EPSG:2326}}$)

As seen above, a multitude of parking restrictions have been violated. To explain the cause, behaviourally 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 critical. The driver's preference is therefore strongly influenced to minimise movement over avoiding fines, hence leading to the common occurrence of illegal parking.

Other than vehicle stoppage inducing traffic congestion, delivery workers of the vehicle also exacerbate traffic congestion:

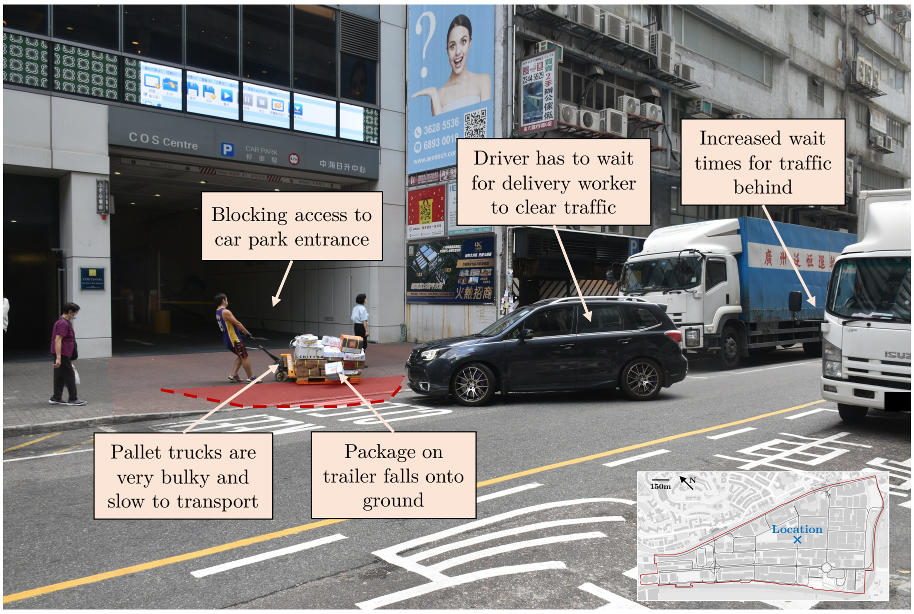

Figure 6.6. Photo of delivery workers blocking the entrance to a car park. (840967,819144$^{\mathrm{EPSG:2326}}$)

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

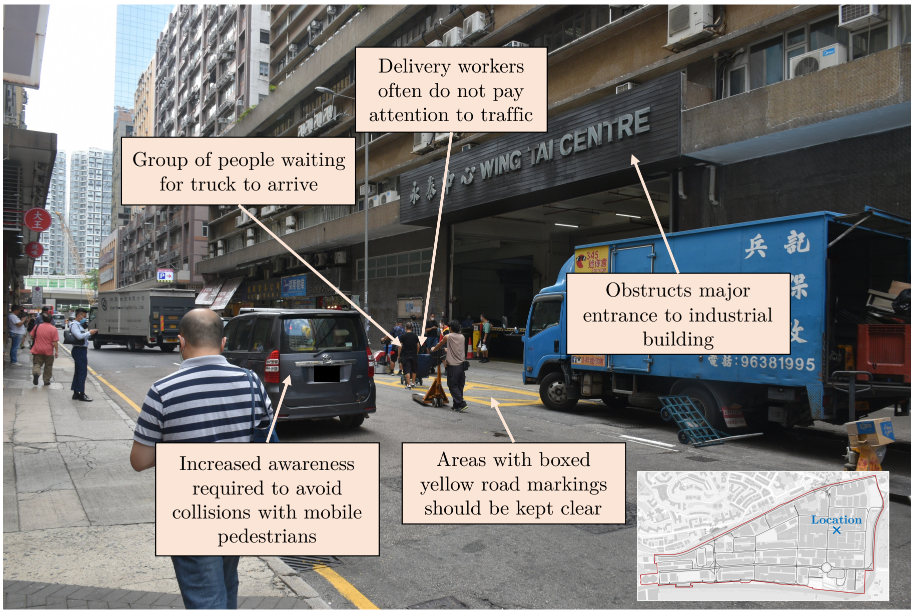

Figure 6.7. Photo of a group of delivery workers congregating, indirectly reducing traffic speed. (841204,818978$^{\mathrm{EPSG:2326}}$)

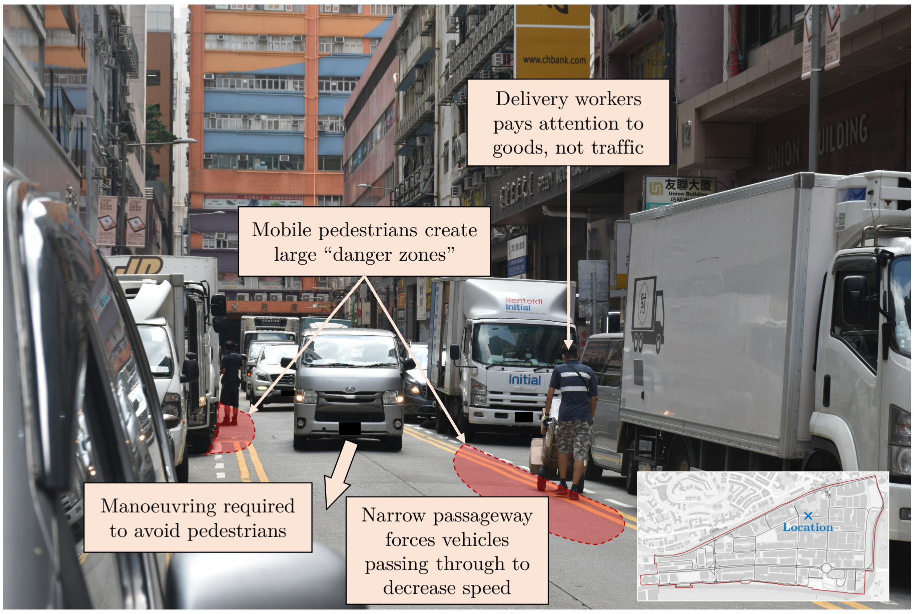

Figure 6.8. Demonstration of how mobile pedestrians cause drivers to slow down significantly. (841140,819200$^{\mathrm{EPSG:2326}}$)

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 massive and further enhanced by monthly-reserved parking packages.

Commented [AC19]: Also add how parking coupons from shopping encourage further use of their parking facility

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

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As explored in Section 6.2.1, industrial vehicles often prefer parking at the immediate location. There are additional factors that can further encourage this behaviour, including

- Use of physical barricades to obstruct on-street parking spots, reflects competitive nature of parking space, explain the wave-like propagating manner of traffic congestion.
- Analyse in detail how the road layout and potential traffic light misconfiguration can contribute to traffic congestion and cause parking accessibility to be less considered by drivers

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$^{\text{EPSG:2326}}$)

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.,

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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 region is extremely scarce and competitive.

6.2.3 Pedestrian interruption of traffic flow

Figure 21. Demonstration of how unloading goods on the wrong side of the road can create bottlenecks in traffic. (841023,818988[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 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

mostly originated from human-based interactions with their surroundings

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

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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.

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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.

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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.

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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 better illustrations!

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7 Evaluation

Although H_0 has been rejected, many errors and assumptions are violated, making the claim questionable.

7.1 Methodology

Fundamentally, the choice of 2SFCA may be flawed. Although it has gained much support from geographers, 2SFCA has only been proposed recently in the 2000s (ref), making results unproven and potentially unreliable. Furthermore, the majority of the existing literature used 2SFCA to assess the equity of healthcare and educational services on a nation-wide scale where distance-decay effects are significant, but never on such a microscopic street-scale level.

NO GUARANTEE!

7.1.1 Unsuitability of selecting a set service catchment distance

7.1.2 Region-wide insufficiency of parking spaces

While the hypothesis states that traffic congestion occurs

- 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

land use specificity, car density, compulsory vs non-compulsory acitivites.

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
- (variable catchment distance 2SFCA) V2SFCA should also be used because commercial/business centres have a much larger catchment distance
- Possible incorporate land use zoning + combine traffic generation/degeneration rates from TPDM 2019!

CAR DENSITY

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 &
- 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

FACTORS AFFECTING ACCURACY

- Land use plays extremely important role in governing whether illegal parking *exists*
  - Industrial activities (strong incentive to park illegally)
  - Commercial activities (reserved parking spaces + regular work schedules)
  - Shopping activities (more to explore!!!)
- Time of day governs which type of activities are dominant
- private carparks + on-street parking spaces are ignored (only 28.2% are open to the public[10]): traffic congestion underestimated.
- model ignores parking cost – in fact many respondents feel like its too expensive to begin with
- familiarity to study area also determines the drivers' potential of cruising.
- Lane selection is inconsistent

FURTHER EXTENSIONS

- Compulsivity of activities -> There are no non-compulsory activities in industrial areas, so scope of study is limited.
- Land use homogeneity -> should include mixed residential/commercial to cover different types of activities, MM2SFCA should be used
- Absolute parking space availability -> macroscopically KT is *overall* lacking spaces (90% respondents say so), not worth to investigate because there are no significant spatial imbalances in parking accessibilities to start with, combined by heavy propagative nature -> overall insignificant.
  - Can expand on the fact that not including parking spaces overall lead to underestimation on the homogeneity of parking distribution.
- V2SFCA??????

8 Conclusion

To be completed

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

9 Bibliography

Initial: https://zbib.org/e02b7bd727f64727801bae0bb2dbe0bf

backup 1: https://zbib.org/d5f2865e0ba547eba78a8fb6d719ec83

backup 2: https://zbib.org/125fccaa2d514778948d96dd6b20c17b

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backup 5: https://zbib.org/275ba48fa0ff479599f1b61216e4be61

10 Appendix

Things to be added:

- Code
- TABLE: All buildings
- TABLE: survey points + spearman rank