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The Inadequacies of Mass Rapid Transit in the Sustainable Transport Drive – the Hong Kong case

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Abstract

Road traffic congestion in Hong Kong is widespread in the downtown areas despite a rapidly growing transport network and is deteriorating in some areas. Land is used inefficiently, leading to less-than-desirable outcomes in population spatial structures and daily traffic jams. The Mass Transit Railway (MTR) Modified Initial System commenced full service in 1980 and the number of stations has since increased more than tenfold. Yet despite serving some areas with serious traffic bottlenecks, the situation has in many cases not improved, and inefficient population clusters remain despite several commuter rail lines. This paper explores the mechanisms that influence the variable success of mass transit on sustainable urban and transport development. Geospatial data from the Hong Kong Government comprising the region's traffic flows, road journey times, road network and its speeds, MTR network and street-block level population characteristics were collected. The relationships between the opening of the MTR's West Island and South Island lines on traffic flows, traffic congestion, population and higher-educated individuals around their vicinity were explored – by means of OLS regressions with difference-in-difference estimators, classic t-tests for difference in means and qualitative examination of the data. The results highlight the lack of a strong link between MTR provision and improvements to congestion as well as potential rigidity in the choice of location of residence.

Contents

An introduction to Hong Kong – an urban & transport perspective

Hong Kong (HK) is a major metropolitan area and special administrative region (SAR) of the People's Republic of China. With a population of 7,336,585 as of 2016 (Hong Kong Census and Statistics Department, 2017) and land area of 1,106 km^2, the former British colony is one of the most densely populated territories in the world, with an average population density of 6,633 inhabitants per square kilometre as of 2016. This is aggravated by mountainous topography and reserved greenspace, with a total developed land area of only 268 km^2 (Hong Kong Civil Engineering and Development Department, 2015). The yields an effective population density of 27,375/km^2. The SAR's very high population density has led to serious consequences and impacts on economic development, especially with regard to developing sustainable transport systems, pollution, accelerated climate warming (Hong Kong Observatory, 2019), livelihood issues and perceived quality of life, government dissatisfaction, and adverse effects on the already fragile political situation.

Many of the effects mentioned above can be attributed in part to the serious traffic congestion and oversaturation of HK's road network, particularly in the central business district (CBD). The SAR government has acknowledged that the situation is deteriorating. While the relatively rural New Territories (one of three main regions of HK) features average vehicle speeds of around 39.9 km/h as of 2013, the densely populated Kowloon and Hong Kong Island (HK Island) see speeds drop to 23.5 and 21.4 km/h respectively, with the busiest roads averaging only 10 km/h (Hong Kong Transport and Housing Bureau, 2015). Due to complex topography, expanding the HK road network at a rate that can keep up with the expected growth rate of vehicles will continue to be impossible (Hong Kong Transport and Housing Bureau, 2015), and could also be counter-intuitive by facilitating HK's recent "private car boom".

To this day however, HK still has one of the lowest per-capita vehicle ownership rates of any developed territory, with only 699,540 registered road vehicles in 2014 (of which private cars make up 495,038). Moreover, the region boasts an world-class network of convenient yet inexpensive mass rapid transit, the Mass Transit Railway (MTR), considered to be among the world's best (Falzon, 2017 and Heelan, n.d.). Much of the population live within walking distance of a metro station. The SAR government has introduced general policies to discourage car ownership, including registration taxes and annual licence fees, but the effects have been insufficient (Cullinane, 2002 and Cullinane & Cullinane, 2003). The construction of new carriageways such as a new bypass tunnel through the CBD has also failed in improving the situation.

The provision of MTR services does seem to have a desirable influence on road traffic flow in some areas (whether by causation or correlation), including some that are populated with a high density. For example, a 2.8-kilometre journey on Kowloon's busiest throughfare takes around six minutes (white arrows, figure 3), while a mere 1.2-kilometre journey on a similar carriageway in HK Island still takes around four minutes (grey arrows, figure 3). These are major carriageways that bring drivers to the cross-harbour tunnel linking Kowloon with HK Island. They both have two to three lanes per direction, a design speed of 70 km/h, and are in the vicinity of the MTR, yet traffic on the HK Island segment moves 36% slower.

There are many potential causes of congestion. Therefore, MTR services alone may be an inadequate substitute for road traffic. The SAR government is planning further expansions to the MTR network in the form of new lines, some of which are under construction. It is crucial to understand where the existing MTR network does well in alleviating road congestion, and where it fails despite having high-volume services in the vicinity. That does not necessarily imply that lines that do not solve the congestion problem fail the cost-benefit test. Rather, by developing insights into the various factors that influence the effectiveness of MTR lines in alleviating congestion, it is possible to identify the locations in which congestion is likely to remain a problem after the completion of new MTR lines, to guide government policy in specific aspects and areas. And quantifying the effects on congestion leads us closer to a conclusion on whether these multi-billion US dollar transport projects are worth their stakeholders' costs.

Brief History of Hong Kong and the MTR

HK has been developing in its modern form since 1898, when the New Territories (refer to figure 1) was leased to the then-British colonial government for 99 years, thus unifying all the territory of modern Hong Kong as a single entity. Development of the territory was suppressed in the former half of the 20th century, with societal and economic development seriously harmed by events such as the Japanese military occupation during WWII and widespread instability in neighbouring China. Only from the 1950s did population and per-capita income start growing at rapid rates. Between 1950 and 1972, HK's population had doubled, and bottlenecks in the road transport network were quickly becoming apparent. The only rail service at the time was the (then-diesel) commuter Kowloon to Canton Railway (KCR) service from central Kowloon to the border with China. The colonial government saw the need to quickly develop rapid transit in the urban areas and commenced comprehensive studies in the 1960s.

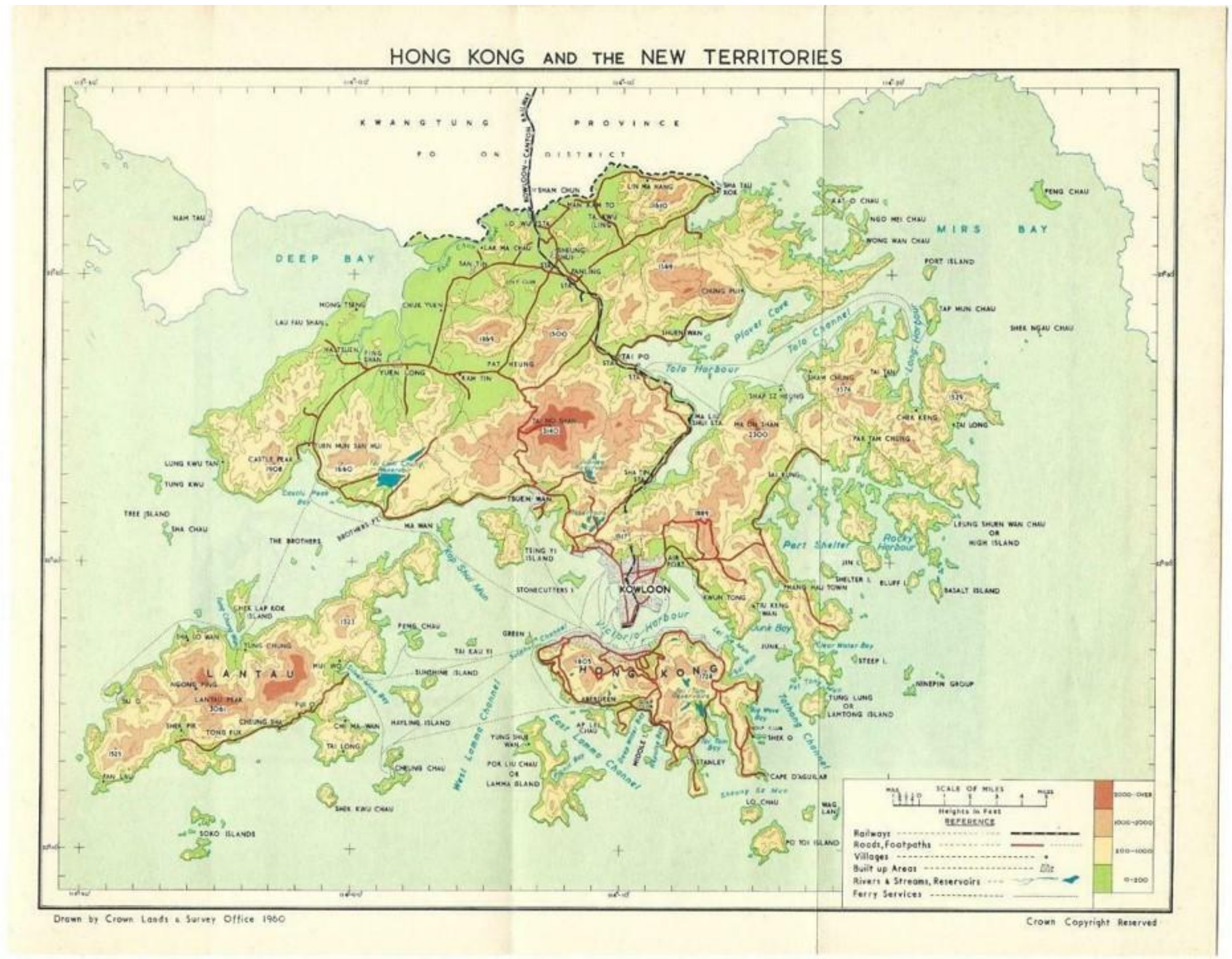

Figure 1 – Hong Kong in the 1960s. The New Territories is the region that is not part of Kowloon (demarcated in purple) and Hong Kong Island (demarcated in grey). "Hong Kong" refers to what is nowadays more commonly known as Hong Kong Island (HK Island). The black line is the KCR, the only railway to exist at the time with stations mainly in the New Territories, of which a large portion was then sparsely-populated farmland or village dwellings (Crown Lands & Survey Office, 1960).

The first line – the Modified Initial System – opened in phases between 1979 and 1980 and ran from Kwun Tong in east Kowloon, through the busy Yau Tsim Wong district and across the Victoria Harbour to the CBD in Victoria (commonly known nowadays as Central) (map in Appendix I). Much of it was underground with bored tunnels – a first for Hong Kong – which greatly limited impacts on the busy road network. The network was quickly expanded; the Tsuen Wan Line to western Kowloon and the urban areas of southern New Territories in 1982, and the Island Line, serving the built-up northern part of HK Island in 1985. Other projects followed in quick succession. The KCR was converted into a metro-like service and merged with the MTR rapid transit network in 2007. In June 2020, the MTR network consisted of eleven lines and carried an average of 3.39 million passengers daily, or 45 percent of the population (Hong Kong Government, 2021). The network as of July 2021 is shown in figure 2.

Figure 2 – MTR network as of July 2021 (MTR Corporation, 2021).

Despite the rapidly expanding network, road congestion has improved only in some areas. In southern Kowloon and the CBD in HK Island (among others), congestion has deteriorated over the past four decades.

Literature review, theoretical framework & research question

Some literature on the economics of public transport and consumer choice may provide insights into the reasons for why mass transit in general fails to alleviate congestion in certain circumstances. One glaring possibility, as expressed by Arnott and Small (1994), is that the elasticity of substitution between cars and rapid transit is relatively inelastic because of the comfort, convenience and privacy of cars compared to mass transit. This is amplified by the phenomenon of failing to account for social costs – even if some individuals substitute away to mass transit, thereby lowering congestion, this will increase the demand for the (now relatively free-flowing) road and draw more road users. This is because private road users do not account for the social cost (congestion) of their usage of the road, but only their private cost. This leads to inefficiency and reduces the overall elasticity of substitution. They also suggest that cars may be preferable in (and suitable to) decentralised cities (as is HK) as commuting needs and routes may be more varied.

Clearly, there are more factors at play than those outlined by Arnott and Small – but this inelastic substitution effect is probably applicable to HK. As disposable incomes increase across the board, car ownership in HK has increased by 70.6% in the last 20 years (Hong Kong Transport Department, 2002 & Hong Kong Transport Department, 2021). Wealthy Hong Kongers (including expatriates) tend to live in villas or other areas that are a distance away from rapid transit, such as on Victoria Peak near the CBD, enjoying the luxuries of bigger homes, less noise pollution and better views. Such individuals require cars for transportation. Also, owning a car is a symbol of status – private car penetration in 2014 was still only 6813 vehicles per 100,000 people. Very high taxes on car importations (Hong Kong Transport Department, n.d.) and most expensive pricing of petrol worldwide that are designed to discourage car ownership are less of a concern for the wealthy. Unsurprisingly, much of HK's congestion occurs in the vicinity of the business districts of HK Island with a high per-capita income (figure 3, blue circles). Yet this does not explain the congestion problems that occur in lower income districts in the Kowloon region such as Mong Kok and Sham Shui Po (figure 3, red circles).

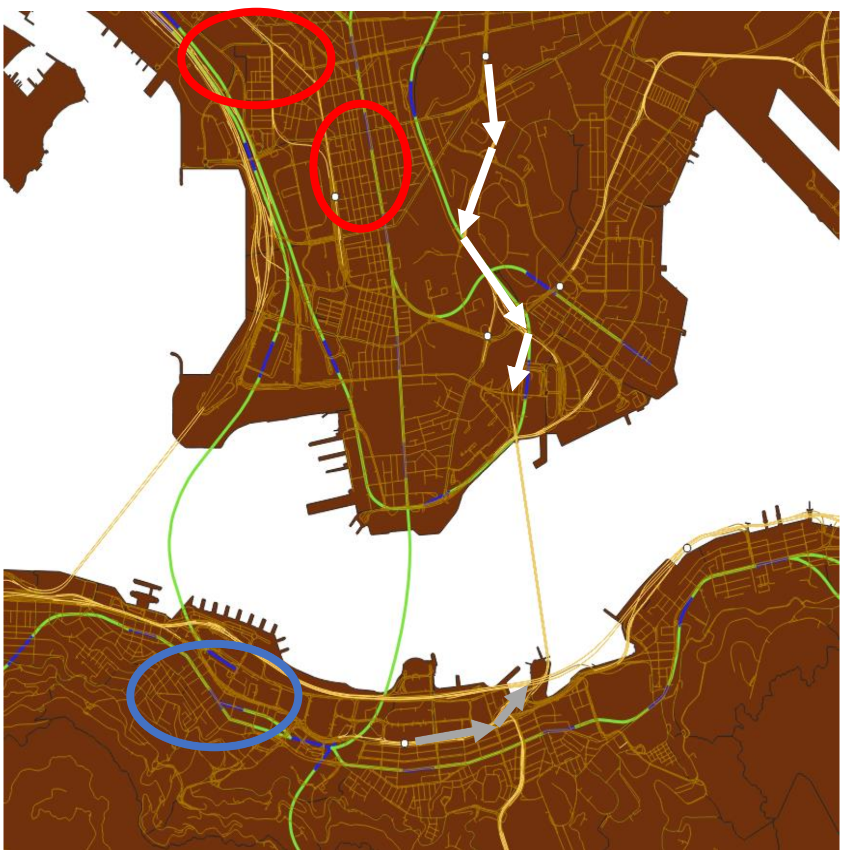

Figure 3 – the journey in Hong Kong Island (grey) takes nearly as long as the one in Kowloon (white) (QGIS, own work)

Pianuan, Kaosa and Pienchob (1994) studied similar congestion problems in Bangkok, where the situation remains serious despite rapidly developing transport infrastructure. The lower but increasing GDP per capita, scale and density of downtown Bangkok may provide useful analogies. Pianuan et al. suggest that the construction of high-standard expressways and flyovers simply led to more private cars and worsening traffic, resulting in limited improvement to congestion. Similarly, in HK, there has been a massive expansion to the motorway network and other roads since the 1980s, including in the urban areas, with a view to improving traffic flow and journey times. Between 1974 and 1993, the length of public roads in HK increased by an average of 2% annually (Hau, 1997), but road congestion did not improve much. The bypass tunnel through the CBD led to minimal improvement in average traffic speed in Hong Kong Island (21.0 km/h in 2017 vs 21.5 km/h in 2019 (Hong Kong Transport Department, 2019 and Hong Kong Transport Department, 2020)). In fact, the number of registered private vehicles rose from 381,757 at the end of 2001 (Hong Kong Transport Department, 2002) to 651,358 at the end of 2020 (Hong Kong Transport Department, 2021), an increase of 70.6% that significantly eclipses HK's population growth of just around 13% during the same period. At the same time, the SAR government significantly expanded the MTR network, bringing the total number of lines up from five to nine (excluding the Disneyland service line and Airport express service which are of negligible relevance to commuters) and extended two existing lines[1]. This, however, was not enough to prevent the huge penetration of private cars. It appears that the construction of new road networks may simply be encouraging more people to own cars, which explains HK's lack of improvement in traffic congestion and the persistent rapid growth in car ownership.

This also leads to another theory. Consider that many of HK's metro lines run alongside major throughfares or even motorways, providing no reason for car users to switch their mode of transport. Yet it is plausible that a metro route that provides a radically more efficient/direct transport link (as opposed to supplementing road infrastructure), and with the potential to provide materially superior journeys for commuters is more effective in deterring car ownership. This may be more effective in alleviating congestion by opening new route possibilities instead of merely providing alternative means of transport to existing ones.

Hau (1997) also suggests that the problem of traffic congestion also comes down to HK's very high population density. Although the amount of road per unit of land area in HK is relatively dense, it is still only half that of Japan's and one third that of Singapore's. This, combined with the SAR's small size, means that the total amount of road able to support the 7.5 million inhabitants of the territory is scarce. This is

[1] As of June 2021 the second phase of the Tuen Ma Line has been opened, linking the West Rail Line and Tuen Ma Line Phase 1 as one line, and the number of lines excluding the Disneyland and Airport lines is now eight. However, the data and hence this paper account for the developments up to and including April 2021 only. The full opening of the Tuen Ma Line involves two new stations in Kowloon, and hence any impacts on variables are expected to be minimal.

exacerbated by the high proportion of mountainous greenspace that cannot be built on due to engineering and legal constraints.

That considered, it can then be understood that congestion in HK is also likely due to sheer population density, which explains why the less-wealthy districts of Mong Kok and Sham Shui Po also suffer from poor traffic speeds. It explains how congestion occurs even with a low per-capita car ownership rate of only around 9% in 2021. The population densities of various districts within HK do vary significantly between each other. The Central and Western district (home to the CBD) has a population density of 19,391/km^2, while for Sham Shui Po it is a staggering 43,381/km^2 (Hong Kong Government, 2017). Districts in the New Territories such as Sai Kung and Tai Po, on the other hand, not only lack congestion problems but also feature relatively low densities of 3,563/km^2 and 2,223/km^2, respectively.

This raises the possibility of mass transit serving a secondary role – to smooth out the differences in population density between the densest districts and more sparsely populated areas. This is because transport enables commuters to travel from distant locations to the CBD more easily, which could increase the demand for housing located further away from the CBD. Such an effect implies that apart from offering more efficient transport routes within busy areas, mass transit routes could also be constructed to serve presently sparsely populated areas, with a view to smoothing out population density and thereby improving congestion. In practice, the MTR (which is also a major property developer) has occasionally engaged in such practices, such as building a rail line to a new housing development area. However, most of the rail network has traditionally served already-densely populated districts. Evidence from Beijing (Zhang & Wang, 2012) shows that investment in public transport can be successful in encouraging land development and the resulting spatial expansion of the urban area under certain conditions. Beijing has a network of commuter rail that connects suburbs to the central district (figure 4). It also may increase demand for housing located away from the CBD but near mass transport links, as housing prices in the CBD increase, resulting in spatial flow into the area. However, Zhang & Wang (2012) express that such a causal relationship is uncertain. They provide the following reasoning:

"Nevertheless, only City Rail exhibited significant influences on the price of nearby residential properties, while BatongLine showed no measurable appreciation from the local housing market. One possible explanation to this difference is the design of the two routes. Unlike City Rail, Batong rail line is sharing the ROW with JingTong Expressway and some segments of the routes are located in the middle of the expressway. The route and inter-changes of the expressway have occupied some of the prime locations which otherwise could be used for integrated transit-land use development in the immediate vicinity of transit stations."

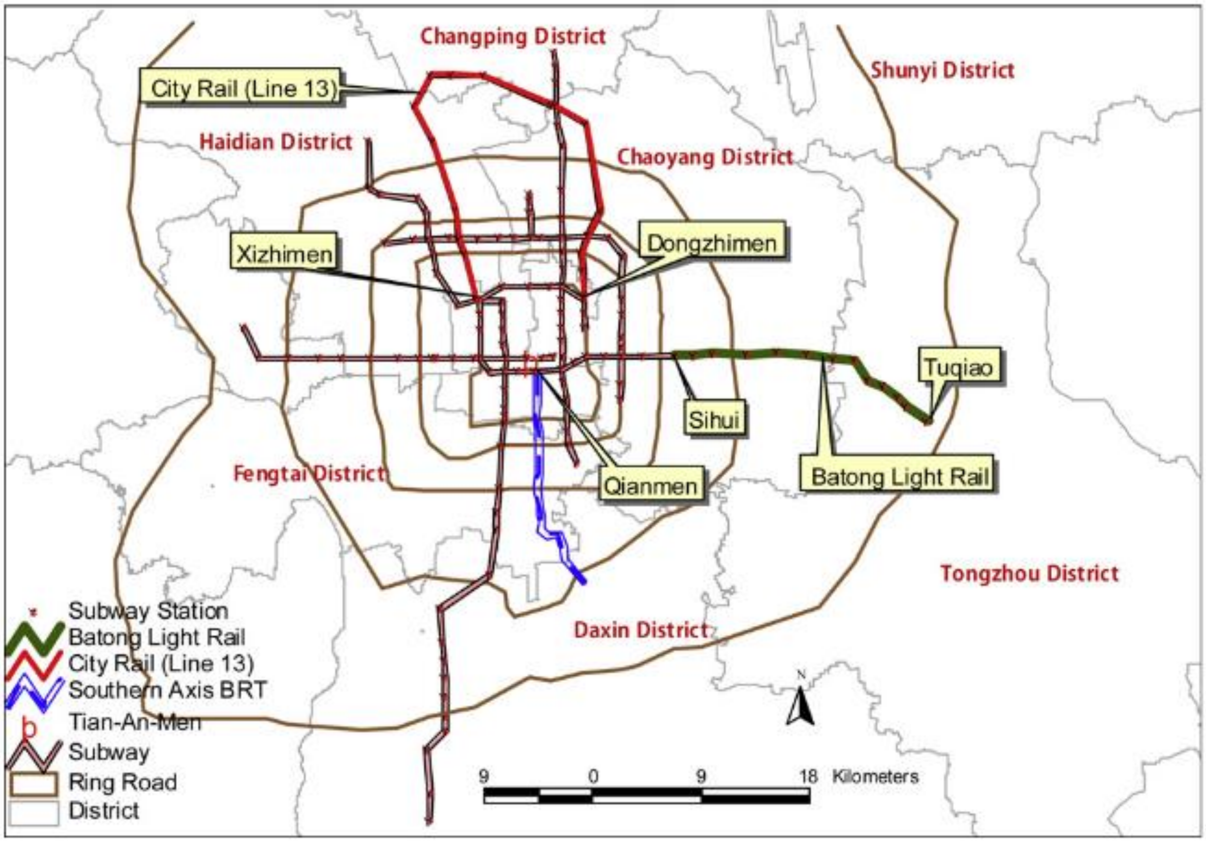

Figure 4 – Beijing rail network (Zhang & Wang, 2012)

This means that for a railway to be effective as a kind of diversion or smoothing of the spatial structure away from the CBD to suburbs, it should serve areas that are prime locations for further land development in addition to serving as an efficient route that beats any present road-based (or other) links. A prime example of such a line in HK, opened recently in 2016, is the South Island Line (SIL).

Research Question

How does the construction of new and efficient mass transit routes to (newly) developing areas reduce CBD congestion and smooth out traffic flow and the population spatial structure? A case on Hong Kong's SIL.

The SIL was opened in 2016 and links the CBD to suburbs in the southern part of HK Island. The route, in particular its direct connection between the CBD and south, is brand-new for any form of transport. The areas served by its non-CBD stations (figure 5; Ocean Park, Wong Chuk Hang, Lei Tung and South

Horizons) also have room for further development and are not seriously overcrowded nor congested, with a population density (Southern District) of around 7,080/km^2 (Hong Kong Census and Statistics Department, 2017).

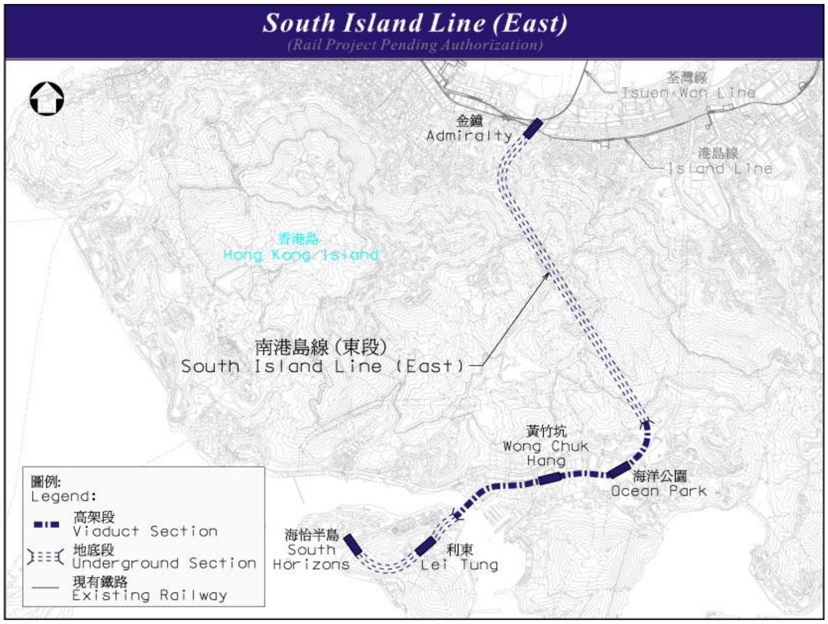

Figure 5 – SIL route in HK Island (Thomas, 2010)

Analysing the SIL requires analysing a control case – the construction of a line that does NOT serve as a radically new and efficient transport route, but merely an alternative to a pre-existing route in an already dense area with high income and car ownership. The West Island Line (WIL) is an ideal contender. Opened in 2015, it is an extension of the pre-existing Island Line that serves Hong Kong Island. The WIL encompasses three stations and the route that it serves is very similar to Route 4 – the motorway that runs across the northwest shore of HK Island (blue line; figure 6 below. Black thin line with yellow rectangles represents rail line and stations). By analysing the differences in the effects of the construction of these lines, it paves the way towards drawing potential (but not certain) causal effects of the type of route that a new line offers. At the very least, certain correlations can be established.

Figure 6 – Map of the WIL and Route 4 in Hong Kong Island (Alchetron, 2018)

Methods & techniques of analysis and research objectives

Data

The Hong Kong Government database was consulted for geospatial data such as population and demographics, road network, traffic flow, metro network etc. The geospatial format is supported by the geospatial analysis software QGIS used for this research, which performs spatial analysis such as calculating distances on a network. The following relevant data were found, depicted in figure 7 below. The purpose of this data will be discussed shortly, and include:

- Demographic factors by area/neighbourhood including population, education level, income etc. (brown) for the year 2011 and 2016.
- Current rail network including stations and track speeds (green with blue stations) as of May 2021.
- Current road network (dark yellow) including those with speed limits other than 50 km/h (light yellow) as of May 2021.
- Annual traffic survey points (pink) – all the points where data for traffic flow (daily average flow over a year) is available, for the years 2013-2019.
- Journey time indicators (white) are several points containing information on the expected time taken to travel from the point to a specific destination at 20:00 hrs on a weekday, as of May 2021.
- Demographic factors by area/neighbourhood including population, education level, income etc. (brown) for the year 2001 (retrospective supplementary analysis)

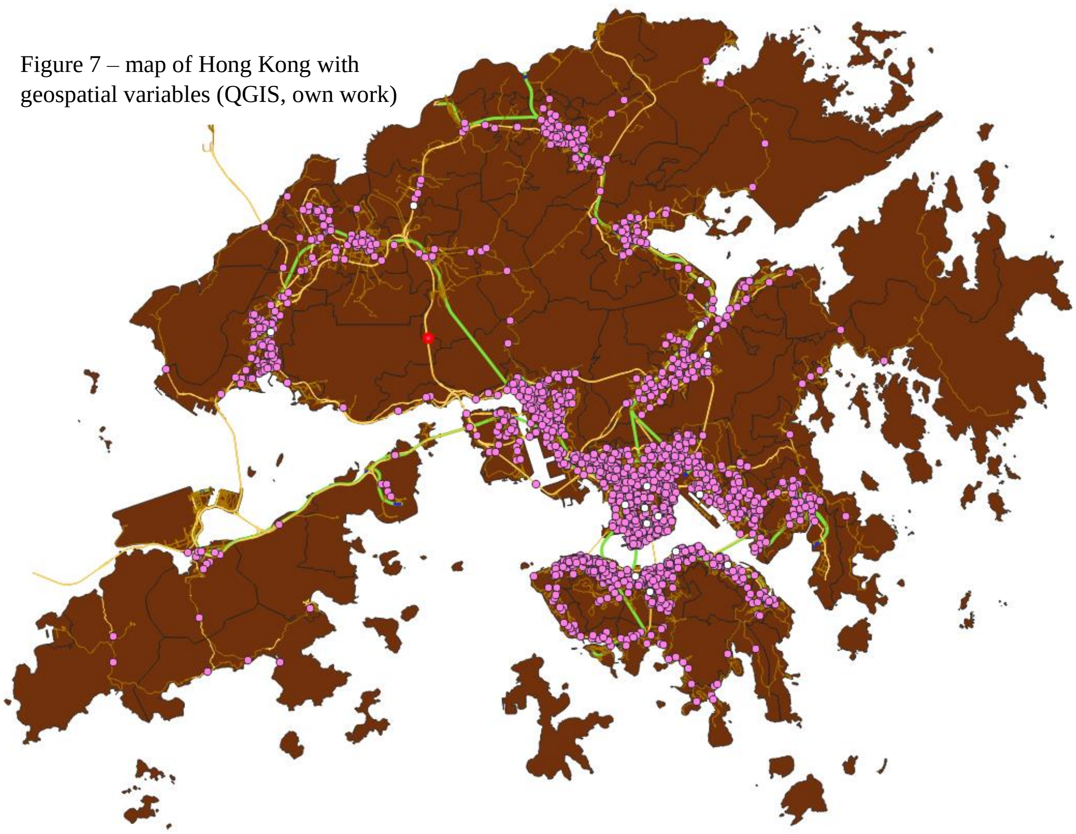

Figure 7 – map of Hong Kong with geospatial variables (QGIS, own work)

We want to understand and quantify the effect the opening of the SIL has had on congestion in the areas that it can provide a viable alternative transport route to (i.e., it must be a route that people would be willing to use), as well as the changes in the spatial structure of the population in general in response to the new transport route.

Overview - analysis of effects of MTR lines on congestion

The first point is the basis of the first hypothesis, although it first needs to be generalised. We can ask the question of what the effect is of constructing a new rapid transit line that provides a new and more efficient alternative to existing road transport (one that connects/serves areas of economic interest or potential development areas), compared to a new rapid transit line that merely supplements an existing transit route in a high-density area. How do we establish what counts as a radically new transport route as opposed to a mere supplement to an existing route? There is no clear-cut distance from a road route at which point a rail route can be said to take a different route as it depends on factors such as the total length of the routes, density of nearby roads etc. However, it is possible to make the general statement that as a rail route becomes *more* distinct from its road-based alternative, its congestion-reducing effect increases. This is clearly the case for the SIL compared to the WIL. Hypothesis 1 is that we should see an effect of the SIL's opening on congestion around the SIL, but only a negligible effect of the WIL's opening on congestion around the WIL. The statistical specification of hypothesis 1 is provided in the model discussion.

Method – estimate congestion using traffic flows

The method of measuring the dependent variable (i.e., congestion) is with reference to the average annual daily traffic flow (AADT) shown as the pink points in the above figure 5. However, each road has a different traffic capacity and therefore using AADT alone to measure congestion is not very informative.

We use the 15 points (white points in figure 7) that provide information about the journey time between that origin point and a specific destination (some have more than one, so $n_{OBS} > 15$). The capacity of the road is represented as its speed limit. Higher speed limits in general correlate with higher-capacity roads in HK[2]. It is expected that increases in AADT alone result in more congestion (i.e., increases in traffic flow for a similar type of road) however the level of AADT that leads to congestion will differ between road types (i.e., speed limits). Faster roads should be able to support a higher AADT level before congesting.

To clarify, the goal is that with the journey times, an OLS regression can be run to estimate effects (regression coefficients) of AADT and the type of road on the degree to which actual and expected travel times differ (i.e., congestion). This model can then be used to estimate congestion for other AADT points and road types using this model.

- For each journey time point, the ratio of the actual journey time from origin to destination to the expected "no congestion" journey time is computed as the "congestion index". The expected journey time without congestion is computed as the time it would take to cover the distance at a speed equal to the speed limits of the relevant road sections. For roads with a 50 km/h speed limit, a speed of 35 km/h is used to account for occasional slowdowns and stops (e.g. traffic lights).
- The *natural logarithm* of the congestion index is estimated as the dependent variable of an OLS regression with the continuous independent variable *ln(AADT)* (the average of all 2019 AADT points along the route), and the interaction effects between *ln(AADT)* and the dummy variables $speed\_limit_{80plus}$, $speed\_limit_{70}$ (speed limit of 50 is the reference category). *ln(AADT)* and *ln(CI)* – logarithmic congestion index – are used in order to approximate relative (percentage) changes, as absolute AADT values vary widely between different road types. The dummy variables represent the most prevalent speed limit of the road section and is representative of the overall (capacity) standard of the route. The interaction effects reflect the fact increases in AADT are expected to

[2] Almost all single-lane (per direction) roads have a speed limit of 50 km/h, even in rural areas. Most roads with a speed limit of 70 km/h are dual carriageways, generally with occasional stops/traffic lights. Roads with a speed limit of 80 km/h or above are reserved for motorways and similar controlled-access carriageways, which generally have three lanes per direction and smooth traffic flow. This speed limit-to-road type relationship is therefore rather consistent.

result in less severe impacts on congestion for high-capacity roads. In other words, the resulting OLS regressors provide the mathematical basis to use AADT and speed limits for estimating (fitting in) congestion on any road in general.

Table 1

Model specification for ln(CI) congestion estimator

Variable – effect on *ln(CI)*
ln(AADT)
ln(AADT)*$speed\_limit_{70}$
ln(AADT)*$speed\_limit_{80plus}$

$$ln\ (Y) = \beta 0 + \ \beta 1 * ln(AADT) + \beta 2 * ln(AADT) * speed\_limit_{70} + ln(AADT) * speed\_limit_{80plus}$$

$H^{CI\_ESTIMATOR}{}_{A\ (I)}$: The ln(AADT) coefficient $\beta 1$ is positive.

$H^{CI\_ESTIMATOR}{}_{A\ (II)}$: The interaction effect ln(AADT) $speed\_limit_{70}$ is negative.*

$H^{CI\_ESTIMATOR}{}_{A\ (III)}$: The interaction effect ln(AADT) $speed\_limit_{80plus}$ is negative.*

Overview – congestion analysis

The congestion analysis on the WIL and SIL cases will incorporate AADT points that are contained within the demographic census areas that the mass transit line as well as the associated highway(s) pass through, excluding the remote mountainous areas under the SIL. The construction of transport infrastructure is most likely to have the greatest influence within these areas. For the WIL, the road route of interest is the section of Trunk Route 4 from its western end to its junction with Connaught Road Central, and for the SIL it includes Harcourt Road, Gloucester Road, and the section of Trunk Route 1 south of the southern end of the Cross Harbour Tunnel. The areas are shown in figures 8 and 9 respectively.

Method – SIL congestion analysis

For the SIL, *ln(AADT)* for the road sections relevant to the line (treatment group) as well as those that are relevant to the WIL (control group) are analysed in the years prior and following the opening of the line. Including the control group helps to exclude exogenous changes by using the difference-in-difference method (DID). The DID method is used because the general congestion situation across HK may be changing over time (i.e., improving or deteriorating). For example, if there is a general worsening trend in the region's congestion, then even if the lines itself have no effect, a simple OLS regression on the lines' effects may give the appearance of the lines having a negative association with congestion, which is spurious due to exogeneity. The DID estimator shows the *difference* in the effect of the lines' opening compared to each other, regardless of the general background trend, which lets us compare the lines' effects *to each other*. The step-by-step process for the SIL is outlined below for clarity:

- Compute *ln(AADT)* of SIL-relevant and WIL-relevant road sections for the years 2013-2019;
- Use *ln(AADT)* to estimate *lnCI* with the mode in Table 1;
- The DID estimator is calculated as the product of the dummy variables $area_{SIL}$ and $year_{SIL}$ (year >= 2017). This is depicted more intuitively in Table 2:

Table 2

Difference-in-difference illustration for change in congestion test (data for illustration purposes)

	$\ln(CI_{SIL\_AADT})$ (treatment group)	$\ln(CI_{WIL\_AADT})$ (control group)	Difference
2013	2.64	1.86	0.78
2015	2.24	1.92	0.32
Change	-0.40	0.06	-0.46

Table 3

OLS regression specification with DID estimator

Variable – effect on *ln(CI)*
$area_{SIL}$
$year_{SIL}$
DID ($area_{SIL} * year_{SIL}$)

The full model specification for the SIL DID is as follows:

- ln(CI): the dependent variable – all WIL- and SIL-relevant congestion points from 2013-2019
- $area_{SIL}$: dummy variable indicating if this lnCI point belongs to the SIL area (0 if WIL)
- $year_{SIL}$: dummy variable indicating if the year is at least 2017
- DID: difference-in-difference estimator equal to $area_{SIL} * year_{SIL}$ (i.e., SIL = 1 and $year_{SIL}$ = 1)

$$ln(Y) = \beta 0 + \beta 1 * area_{SIL} + \beta 2 * year_{SIL} + \beta 3 * area_{SIL} * year_{SIL}$$

$H^1{}_{A\,(I)}$: *The DID coefficient,* $\beta 3$*, that is for the variable* $area_{SIL} * year_{SIL}$ *is negative.*

Method – WIL congestion analysis

For the WIL a different approach is used[3]. It is expected that the opening of the WIL has not reduced congestion in the area; it is expected that the opening of the WIL has a negligible effect on *ln(CI)*. It is therefore expected that the changes in *ln(CI)* in the WIL areas from 2013 to 2015 is the same as the change in *ln(CI)* in the SIL areas during the same period. The congestion in each area may have increased or decreased in line with the general background trend across HK, but the change *between* the two lines is expected to be equal.

To test this, a $change_w$ variable is used which is defined as the ln(CI) of WIL areas in 2015 minus the ln(CI) of WIL areas in 2013. Similarly, $change_s$ is the ln(CI) of SIL areas in 2015 minus the ln(CI) of SIL areas in 2013. Then, a two-sample t-test with unequal variances (we cannot assume they are equal) is performed. The 95% confidence interval of the difference provides an indication of whether a *large* effect can be ruled out. In this case, the difference in change in ln(CI) is considered to be *small* if its confidence interval lies in the range [-0.020, 0.020]; meaning it is possible to reject that the difference of the effect on the congestion index of 2 percent or greater[4]. This is not a positive statement that there *is no* effect of the opening of the WIL on congestion, but rather that the statistical effect of the WIL is weak and not meaningful on society. The technical model is as follows:

Two-sample unpaired, unequal variance t-test for difference in the means of $change_w$ & $change_s$

$H^1_{A\,(II)}$: *The absolute value of the difference in the mean of $change_w$ and $change_s$ is less than 0.01.*

Brief summary – congestion analysis

- Investigate the effects of the opening of the SIL and WIL on traffic congestion around the areas they influence (serve)
- The WIL case is considered the baseline (control) case and is representative of HK's overall trend
  - The change in *ln(CI)* of AADT congestion points in the WIL areas is expected to be similar
- The SIL case is considered the treatment case and is therefore compared to the WIL
  - test if *ln(CI)* around AADT congestion points is lower if such a point is in the SIL area *and* if the year of the AADT measurement is such that the SIL is open (DID estimator)

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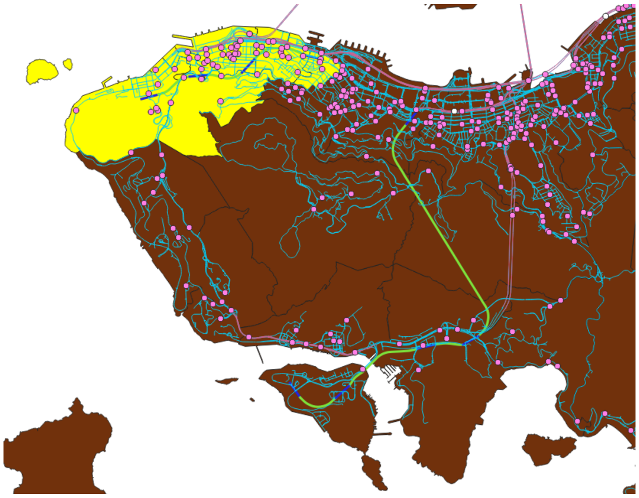
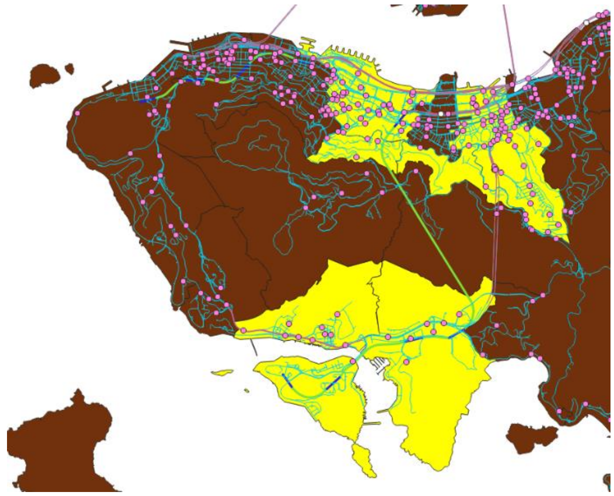
[3] A different test is needed here because while an insignificant DID estimator indicates that the null hypothesis should not be rejected, it doe not imply that we should *accept* it nor does it provide an indication as such. For example, if standard errors are large, this increases the likelihood of an insignificant p-value which does little to affirm that the effect is zero.

[4] Assume a rather congested road with a congestion index of 4, meaning traffic moves only at a quarter of the speed limit, which is not uncommon in HK Island. *ln(CI)* is 1.38629436. A drop in *ln(CI)* to 1.36629436 implies a drop in the congestion index to exp(1.36629436) = 3.92. Assume a 2000-metre road with a speed limit of 50 km/h (13.89 m/s). The expected travel time is 2000/13.89 = 144 seconds. The old travel time is 144∗4 = 576 seconds (12.5 km/h), while the new time is 72∗1.485 = 564 seconds (12.8 km/h), which is considered a bare minimum improvement.

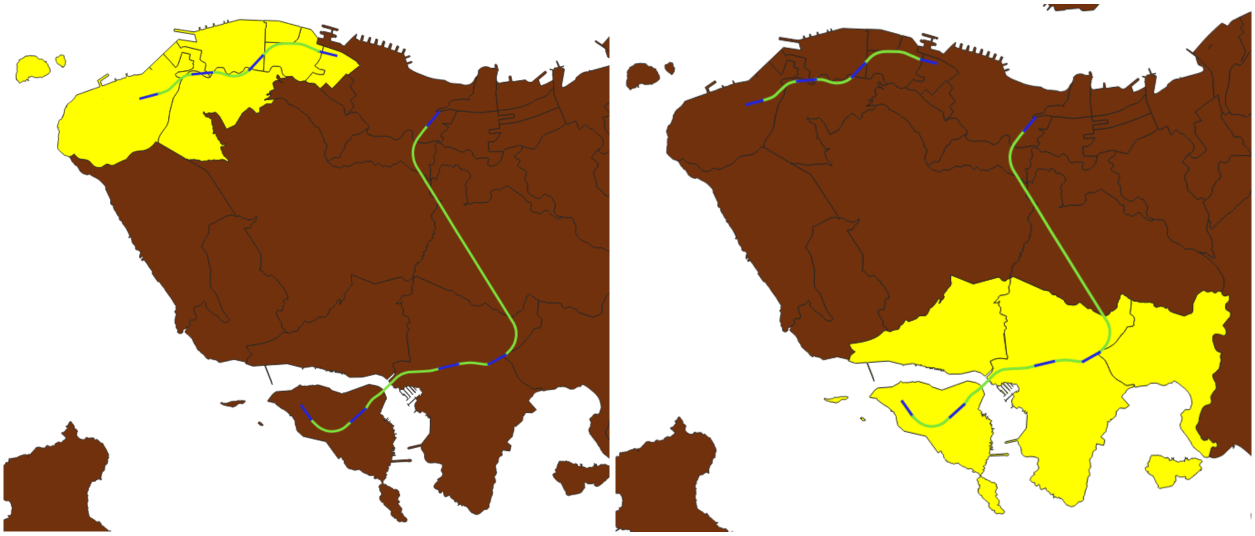



Figures 8 and 9 – map of area of interest (WIL left, SIL right). The lines are depicted in green, stations are blue lines, pink points are AADT points (QGIS, own work).

Overview – changes in spatial structure before and after the opening of both lines: population

The second hypothesis concerns changes in spatial. Our theoretical framework suggests that rapid transit routes can help smooth out the population structure if they serve areas that have high development potential, while those that serve already dense areas are less likely to result in any improvements. The WIL was built in a rather densely populated district (Central and Western District; 19,391/km^2), while the Southern District served by the SIL has a much lower population density (7,080/km^2) (Hong Kong Census and Statistics Department, 2017). There is more room for further development in the areas served by the SIL (except for around the CBD station, Admiralty).

As town-level demographic data is available for the years 2011 and 2016, it is expected that the areas served by the SIL (except for Admiralty) show an increase in population in 2016 compared to 2011, while those served by the WIL show no significant difference, adjusted for population growth rate. More generally, areas around a new rapid transit line with high potential for development should see greater increases in population than areas that do not, adjusted for the average population growth rate. In this case, "areas around a new line" are defined as the towns in the demographic data that the new lines pass through. For the SIL an additional area just to the southeast of the line is also included as transport services there were limited prior to the line's inauguration. This is hypothesis 2 – there is expected to be a movement of population into the SIL areas that is significantly greater than the movement into the WIL areas.



Figures 10 and 11 – Areas of interest (spatial structure) (WIL left, SIL right) (QGIS, own work)

Method – spatial structure part 1: population changes

The SAR's population is in general growing every year, so it is expected that the population in the areas near the WIL would have also grown from 2011 to 2016. Therefore, a difference-in-difference method analogous to hypothesis 1 is used to evaluate the difference in population growth between the two regions[5]. This shows if the population movement into the SIL is significantly higher than that of the WIL. This is done by looking at the changes in the populations of the relevant areas between 2011 and 2016. Table 3 shows an example.

$$ln\ (population) = \beta 0 + \beta 1 * area_{SIL\ (2)} + \beta 2 * year_{2016} + \beta 3 * area_{SIL\ (2)} * year_{2016}$$

H^2_A: The DID coefficient, $\beta 3$, that is for the variable $area_{SIL\ (2)} * year_{2016}$ is positive.

Overview - changes in spatial structure before and after the opening of both lines: demographics

Finally, it is also useful to know not only how the population structure changes, but also the *type* of people that move between places. Our theory suggests that wealthy individuals do not respond much to rapid transit as much as the general middle-class, as they tend to live in exclusive areas and drive cars for commuting as well as leisure purposes. In technical terms, this could be understood as the cross-price elasticity between road and rail transport being lower for wealthy individuals than it is for poorer individuals.

[5] In the regression equation, the number (2) in parantheses means that this is the group of SIL areas used for spatial structure analysis as opposed to the that of which was used in the congestion analysis.

The proportion of higher educated (with a university degree) individuals is available for each area. Having a university degree is positively correlated with higher income. Such individuals are expected to respond less to public transport provision.

Method – spatial structure part 2: demographic changes

The population is split into lower-income (no degree) and higher-income (has a degree) groups, and the movement of each group of population between 2011 and 2016 is analysed. It is expected that there will not be significant movement in the WIL areas, but the areas served by the SIL are expected to involve an inflow of people who mainly do not belong to the higher-educated type, which is reflected as a decrease in the proportion of higher-educated individuals relative to the WIL areas. This is also because the areas served by the SIL are generally middle-class with standard housing and plenty of blue-collar industry. Also, wealthy individuals tend to drive cars. This is shown intuitively in Table 4 below:

Table 4

Difference-in-difference of logarithmic population/proportion on higher-educated people (EDUC_PROP)

	$area_{SIL\ (2)} = 0$	$area_{SIL\ (2)} = 1$	Difference
$year_{2016} = 0$	xx.xx	xx.xx	xx.xx
$year_{2016} = 1$	xx.xx	xx.xx	xx.xx
Change	xx.xx	xx.xx	xx.xx

$$EDUC\_PROP = \beta 0 + \beta 1 * area_{SIL\ (2)} + \beta 2 * year_{2016} + \beta 3 * area_{SIL\ (2)} * year_{2016}$$

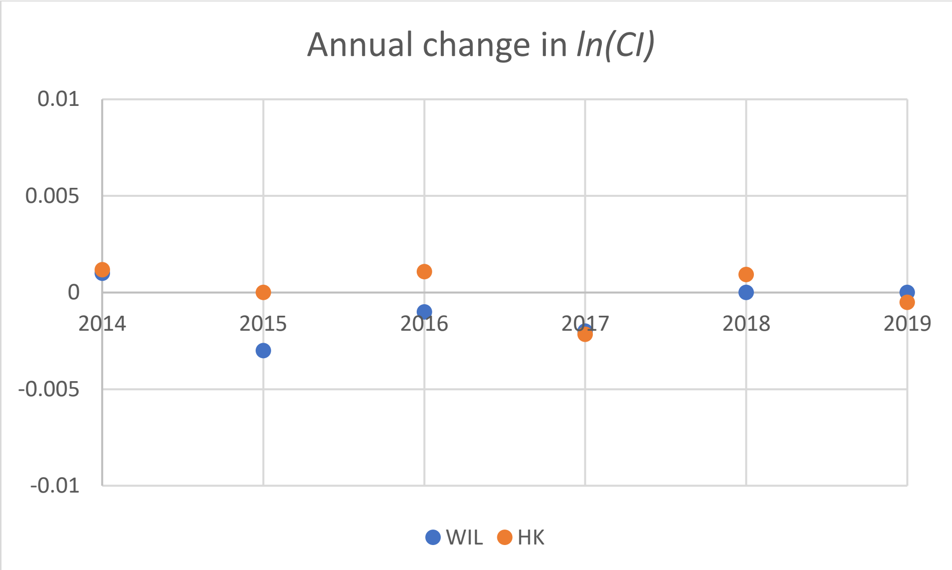
H^3_A: *The DID coefficient,* $\beta 3$*, that is for the variable* $area_{SIL\ (2)} * year_{2016}$ *is positive.*

If we do not observe much movement among wealthy individuals, it is likely that they do not readily substitute road for rail transport and do not move in response to the opening of the new line. Hence, congestion in the wealthy areas does not decrease (i.e., those near the WIL).

Statistical results and interpretations

WIL area congestion compared to the rest of HK

Graph 1 visualises the assumption that the WIL congestion trend is representative of HK's general trend.



Graph 1 – change in *ln(CI)* compared to the previous year (own work).

Aside from the apparently small magnitude of the effects of the WIL, the trend in the WIL areas is very similar to that of HK overall. Therefore, the WIL is representative of HK in recent years.

Statistics – estimation of congestion index

Table 5

Congestion index estimation model

R-squared: 0.225, n = 32

	Coefficient (exp(coef.))	Robust std. error	p-value
ln(AADT)	0.271 (+31.13%)	0.237	0.262
ln(AADT)*$speed\_limit_{70}$	-0.022 (-2.18%)	0.014	0.132
ln(AADT)*$speed\_limit_{80plus}$	-0.046** (-4.50%)	0.017	0.014
Constant	-2.275		

Note. This table describes the effect of the natural logarithm of average AADT on an origin-destination pair (route) and its interaction with road types (speed limit 70 and speed limit 80+, reference category speed limit 50) on the natural logarithm of the congestion index of the route (its actual recorded travel time divided by its expected journey time if vehicles maintained a speed equivalent to the speed limit of the road (or 35 km/h if the limit is 50 km/h)). The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

Interpretation – estimation congestion index

The OLS regression analysis reveals that there is a positive effect of traffic flow on congestion. Specifically, a 100% increase in AADT is associated with a 31.13% increase in the ratio of actual travel time to expected travel time. However, the effect is not statistically significant to the 5% level. Regarding the interaction effects, the effect of a 1% increase in AADT on the relative change in congestion index is -2.18 percent for a route where the speed limit is generally 70 km/h (not statistically significant) and -4.50 percent where the speed limit is generally 80 km/h or higher (significant to the 5% level). This is in line with the expectation that congestion is less serious on roads with higher traffic capacity for a given level of traffic flow.

The R-squared value implies that the model accounts for only 22.5% of the congestion experienced on roads. It is likely that there are certain exogenous factors not accounted for that also have significant effects on road congestion, such as a high number of merging activities, heavy vehicles or tunnel tollbooths. Nevertheless, the signs of the effects are in line with expectations (positive for AADT, negative for its interaction effect with high-speed roads but still with an overall positive effect). The lack of a significant effect may be due to the limited number of origin-destination pairs (n = 32), unfortunately no more are available. Given the theoretical evidence that excess traffic flow is a significant driver of traffic congestion and considering the directions of the effects and the significant interaction effect with high-speed roads, there appear to be reasonable grounds to using AADT as a measure of congestion. Although not directly pertinent to the topic at hand, it also became apparent that the model predicts realistic percentages of speeding drivers (see footnote 4 on page 20). However, it is noted that this is a point of research that should be substantiated further and more conclusively.

Statistics and interpretation - effect of WIL opening

Table 6

Unpaired two-sample t-test difference estimator for the opening of the WIL on ln(CI)

	n	Mean	Std. error	95% conf. int.
$change_w$	54	-0.002	0.003	[-0.008, 0.004]
$change_s$	119	-0.003	0.002	[-0.007, 0.001]
Combined	173	-0.003	0.002	[-0.006, 0.001]
Difference		0.001	0.004	[-0.007, 0.008]

Note. This table describes the difference in the means of the changes in WIL- and SIL-area ln(CI) before and after the opening of the WIL. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

The 95% confidence interval of the difference in changes is within the range [-0.010, 0.010], implying that the effect of the WIL on its surrounding areas is small. Moreover, the opening of the WIL also appears to have no effect on congestion in general, with the mean of $change_w$ close to zero. This implies that the opening of the WIL has had almost no effect on reducing excess traffic flow. This is in line with expectations because the WIL rapid transit route does not offer a radically different transport route and serves an area with a relatively high per-capita ownership of cars.

Statistics - effect of SIL opening

Table 7

DID estimator for the opening of the SIL on ln(CI)

R-squared: 0.057, n = 692

	Coefficient (exp(coef.))	Robust std. error	p-value
$area_{SIL}$	0.137 (+14.7%)	0.031	0.000
$year_{SIL}$	-0.003 (-0.3%)	0.032	0.925
DID	-0.005 (-0.5%)	0.042	0.905
Constant	0.204		

Note. This table describes the difference-in-difference effect of the opening of the SIL on the average of the logarithmic congestion index of the road sections in the SIL areas compared to the WIL areas. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

Table 8

DID estimator for the opening of the SIL on ln(CI) (only main road routes)

R-squared: 0.057, n = 68

	Coefficient (exp(coef.))	Robust std. error	p-value
$area_{SIL}$	0.243 (+27.5%)	0.124	0.147
$year_{SIL}$	-0.003 (-0.3%)	0.118	0.984
DID	-0.003 (-0.3%)	0.110	0.983
Constant	0.185		

Note. This table describes the difference-in-difference effect of the opening of the SIL on the average of the logarithmic congestion index of the road sections of major trunk routes in the SIL areas compared to the WIL areas. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

Contrary to theoretical expectations, no DID effect was observed for the SIL's opening. The DID coefficient of -0.005 for all road routes in the relevant areas as well as -0.003 for those that are main routes only are statistically insignificant to all levels. Moreover, the coefficient of the effect of the opening of the SIL ($year_{2017}$) is also close to zero.

Additional tests - change in congestion in 2013-2015 and 2015-2017 for WIL and SIL areas

To investigate this further, a simple paired t-test for difference in means is computed for the 2013-2015 as well as 2015-2017 logarithmic congestion indices for both the WIL and SIL. Descriptive statistics for congestion are given in Table 8 and the statistical test results are given in Table 9 and 10 below:

Table 9

Descriptive statistics of congestion (non-logarithmic) in each area and each year

Variable	n (main routes)	Mean	Std. dev.	Minimum[6]	Maximum
$CI_{(WIL, 2013)}$	54 (3)	1.253	0.256	0.590	1.910
$CI_{(WIL, 2015)}$	54 (3)	1.245	0.253	0.607	1.933
$CI_{(WIL, 2017)}$	54 (3)	1.246	0.253	0.614	1.928
$CI_{(SIL, 2013)}$	119 (14)	1.470	0.411	0.577	2.593
$CI_{(SIL, 2015)}$	119 (14)	1.466	0.408	0.577	2.540
$CI_{(SIL, 2017)}$	119 (14)	1.455	0.404	0.582	2.531

Note. Here CI is the raw ratio of estimated actual travel time to expected travel time (non-logarithmic).

Table 10

Paired t-tests for difference in means between regions and years:

Variables	Difference in means (exp(dif.))	Std. error of difference	95% conf. interval	p-value one-sided (Pr[T < t])
WIL_lnCI_2013, WIL_lnCI_2015	-0.002 (-0.2%)	0.003	[-0.008, 0.004]	0.249
WIL_lnCI_2015, WIL_lnCI_2017	-0.003 (-0.3%)	0.004	[-0.011, 0.005]	0.211
SIL_lnCI_2013, SIL_lnCI_2015	-0.003 (-0.3%)	0.002	[-0.007, 0.001]	0.094*
SIL_lnCI_2015, SIL_lnCI_2017	-0.007 (-0.7%)	0.002	[-0.010, -0.004]	0.000***

Note. This table describes the difference-in-means of the WIL road route congestion points (logarithmic congestion index) between 2013 and 2015, and 2015 and 2017, and likewise for the SIL points. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

[6] It is possible and even expected for there to be instances where the estimated congestion index is slightly below 1 or even significantly below 1 because minor speeding (<= 10 km/h) is relatively common on roads with smooth traffic flow (e.g., expressways) and tolerated by the police, while more serious speeding occurs occasionally. Of the 692 road segments estimated, 51 have a CI between 0.88 and 1.0 (approx. <= 10 km/h), yet only 31 have a CI below 0.88, and only 16 have a CI below 0.72, which corresponds to a serious speeding offence (>= 40%). In effect, the regression models the total speeding rate as being 11.8%, minor speeding as being 7.4% and serious speeding 4.5%. This attests to the model's predictive potential.

Table 11

Same as Table 10, but main routes only:

Variables	Difference in means (exp(dif.))	Std. error of difference	95% conf. interval	p-value (Pr[T < t])
WIL_lnCI_2013, WIL_lnCI_2015	0.002 (+0.2%)	0.003	[-0.011, 0.014]	0.694
WIL_lnCI_2015, WIL_lnCI_2017	-0.003 (-0.3%)	0.013	[-0.061, 0.054]	0.421
SIL_lnCI_2013, SIL_lnCI_2015	0.010 (+1.0%)	0.002	[0.003, 0.016]	0.996
SIL_lnCI_2015, SIL_lnCI_2017	-0.006 (-0.6%)	0.004	[-0.014, 0.003]	0.088*

Note. This table describes the difference-in-means of the WIL (WIL) road route congestion points (main routes only, logarithmic congestion index) between 2013 and 2015, and 2015 and 2017, and likewise for the SIL (SIL) points. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

These results offer a conclusion not much different than the DID test in a practical sense. When taking all routes into account, the opening of the WIL and the SIL has no significant effect on congestion in the WIL areas ($p > 0.10$). On the other hand, the opening of the WIL (SIL_lnCI_2013/15) has a small negative effect on congestion in SIL areas to a 10% significance level. More crucially, there is a negative effect of the opening of the SIL on congestion within its areas ($p < 0.01$). When considering main routes alone, no significant effects are observed on the WIL road-route-equivalents with the opening of either line; neither does the opening of the WIL affect congestion on the SIL's route of interest. However, the opening of the SIL has a small but somewhat significant ($p < 0.10$) negative effect on congestion around its main route. Nonetheless, the magnitudes of the effects are so small (under 1 percent) that it is not considered to be practically relevant (although it is statistically significant)

Interpretation - SIL effects

The lack of a statistically significant DID effect but the indication of a decrease in congestion when considering differences in means alone raises the question of whether the decrease in mean for the SIL is due to an exogenous decrease in road usage/congestion across HK overall. If such a decrease can be ruled out, then it is more plausible that the effect of the SIL on road congestion exists in practice, although it is very small. A test of the change in the mean of the congestion index in HK reveals a slight increase in the average congestion across the region (significant to the 5% level):

Table 12

Difference in mean of logarithmic congestion index before and after road opening

Variables	Difference in means (exp(dif.))	Std. error of difference	95% conf. interval	p-value (two-sided)
lnCI_2015, lnCI_2017	0.007 (+0.7%)	0.003	[0.001, 0.013]	0.018**

Note. This table describes the difference-in-means of road route congestion points (logarithmic congestion index) between 2015 and 2017 over all of Hong Kong. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

It appears that there is some effect of the SIL's opening regarding congestion on a local level when compared to the overall trend across HK. The possibility that the road transport around the WIL has a stronger connection with the SIL than expected is excluded because the high-speed AADT points were excluded from the WIL areas, thereby excluding inter-district carriageways between the WIL and SIL areas. Their alignment also makes this possibility unlikely because they would only serve such a purpose for drivers coming from areas further away such as West Kowloon and beyond. It is unlikely that such commuters make up more than a fraction of the total commuters as it involves travel between non-CBD origin and destination. Table 10 shows that even by 2017, after an "adjustment period" of a couple years, the congestion around the WIL areas remains similar. It is therefore not considered likely for the traffic flows around the SIL areas to have changed much after 2017. In other words, there appears to be a degree of rigidity to commuting flows at the aggregate level. This point warrants further investigation.

Overview - changes in spatial structure

For the testing of hypothesis 2, the relevant districts are subdivided into their smaller street block groups based on finer demographic data provided by the HKSAR government (refer to Appendix II for QGIS map). This is to ensure that a sufficient sample size of populations is used for statistical testing. Below are some descriptive statistics the areas of interest:

Table 13

Descriptive statistics of demographic features of each area, 2011 and 2016

Variable	n	Mean	Std. dev.	Min	Max
$POP_{(WIL, 2011)}$	119	1592.773	1348.801	409	8937
$POP_{(WIL, 2016)}$	121	1491.653	1413.331	408	8962
$POP_{(SIL, 2011)}$	45	3632.422	5558.862	413	24150
$POP_{(SIL, 2016)}$	50	3278.4	5056.224	429	24103

$EDUC\_POP_{(WIL, 2011)}$	119	0.364	0.199	0.050	0.8
$EDUC\_POP_{(WIL, 2016)}$	121	0.442	0.218	0.064	0.8
$EDUC\_POP_{(SIL, 2011)}$	45	0.323	0.230	0.017	0.8
$EDUC\_POP_{(SIL, 2016)}$	50	0.384	0.252	0.021	0.8

Note. Guide – pop, population; educ_prop, ratio of higher-educated individuals to total population.

The population of the areas around the WIL decreased by around 4.8%, while that of the SIL increased by 0.3%. Across the whole of Hong Kong Island, population decreased from 1,270,876 to 1,253,417 (decrease of 1.4%). This indicates potential relative movement towards the SIL areas, but also an outflow from the WIL. This will be addressed in more detail after DID analysis.

The proportion of higher-educated individuals increased by 7.8 and 6.1 percentage points respectively in the areas. These figures are higher than the overall trend across Hong Kong Island, where there was an increase of 4.1 percentage points (from 23.4% to 27.5% (297,602 to 345,466)).

Statistics - changes in spatial structure: population

Table 14

Difference-in-difference in logarithmic population in each area before and after opening of SIL

R-squared: 0.036, n = 335

	Coefficient (exp(coef))	Robust std. error	p-value
$area_{SIL\ (2)}$	0.315 (+37.03%)	0.174	0.071*
$year_{2016}$	-0.099 (-9.43%)	0.082	0.230
DID	0.018 (+1.82%)	0.239	0.941
Constant	7.154		

Note. This table describes the difference-in-difference effect of the opening of the SIL on the average of the logarithmic population in the SIL areas compared to the WIL areas. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

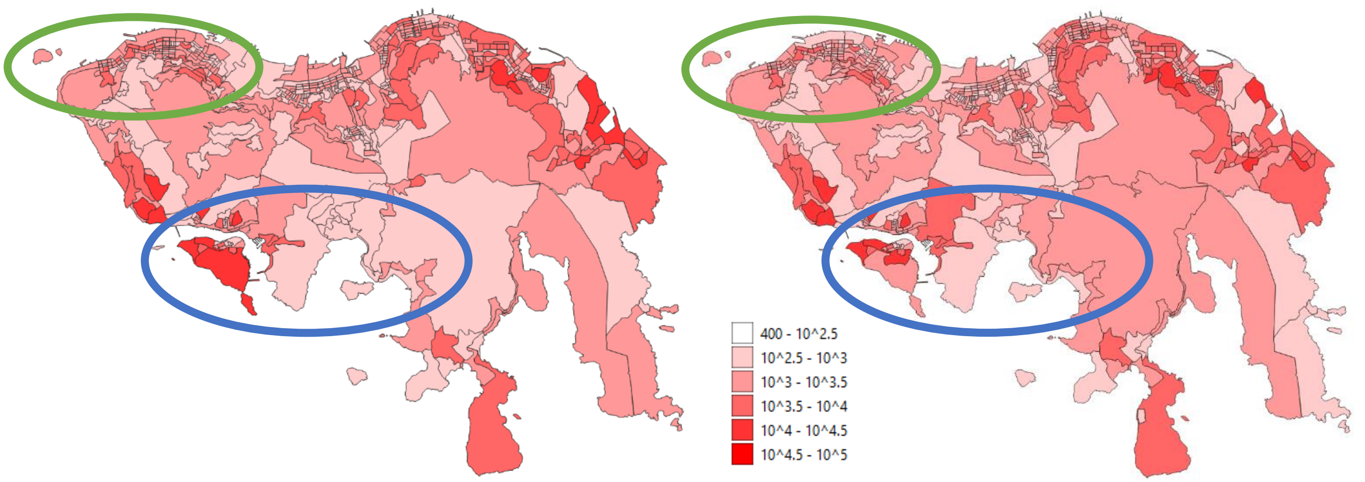


Figure 12 – population in different areas in 2011 (left) and 2016 (right) in Hong Kong Island. WIL/SIL areas circled in green/blue respectively (QGIS, own work).

There is no significant difference in the difference in the change in population between the two areas from 2011 to 2016 in terms of the OLS regression statistic. The change in spatial structure is visualised in figure 12. From both the statistics and figures there appear to be no significant changes in overall population structure before and after the opening of the lines.

Statistics - changes in spatial structure: demographics

Table 15

Difference-in-difference in proportion of higher-educated individuals in each area before and after the opening of the SIL

R-squared: 0.037, n = 335

	Coefficient	Robust std. error	p-value
$area_{SIL\ (2)}$	-0.041	0.039	0.286
$year_{2016}$	0.078	0.027	0.004***
DID	-0.016	0.056	0.770
Constant	0.364		

Note. This table describes the difference-in-difference effect of the opening of the SIL on the proportion of higher-educated individuals in the SIL areas compared to the WIL areas. The stars for p-values: * < 0.10; ** < 0.05; *** < 0.01.

The difference in the change in the educated proportion between the two areas is also not significant, however there is a significant (1% level) increase in the higher-educated population overall over the two areas – an increase of 7.8 percentage points. As noted before, this change is significantly different compared to the overall trend across Hong Kong Island. Figure 13 below depicts the changes visually.

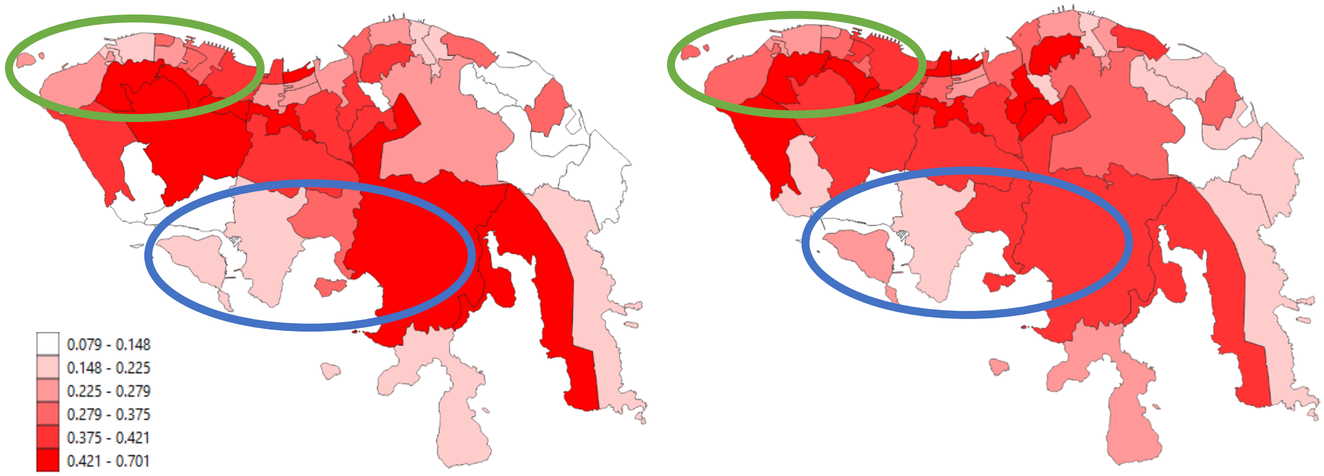


Figure 13 – changes in proportion of higher educated population (proportion) from 2011 to 2016 (QGIS, own work).

Interpretation - changes in spatial structure: population

It is possible that a lack of observed significant change in the population around the SIL areas is due to the response to new transport being slower than expected. Although the area has developed between 2011 and 2016 in response to the construction of the SIL, it is plausible that certain demographic changes would not be realised for several years. Supplementary analysis on the opening of the Ma On Shan Line (MOL) in 2004 (now part of the Tuen Ma Line) with a longer period of three years before opening to seven years after opening is hereby performed (2001-2011, as detailed demographic data is released every year ending in 1 and 6). The MOL areas are demographically similar to the SIL areas regarding income, education etc. Data for 2001 is only available for the larger district divisions instead of street block groups, so robust statistical analysis is not considered to be meaningful, although a simple DID table on logarithmic population illustrates the developments:

Table 16

Difference-in-difference in change in ln(POP) of in each area before and after the opening of the MOL

	$area_{MOL}$ = 0 (rest of HK)	$area_{MOL}$ = 1	Difference
2001	15.637	12.802	-2.835
2011	15.712	12.911	-2.801
Change	0.075	0.109	0.034
Actual change (exp(change))	7.79%	11.52%	3.73%

Note. $n_{(2001, MOL=1)}$ = 21, $n_{(2011, MOL=1)}$ = 23, $n_{(2001, MOL=0)}$ = 363, $n_{(2011, MOL=0)}$ = 389

Over a 10-year period, the change in population between the two areas is more apparent, with the MOL areas growing 48.9 percent faster than the rest of HK. This phenomenon, if statistically significant, would be consistent with theoretical expectations, although rigorous statistical testing is required to establish the veracity of the purported effect.

Interpretation - changes in spatial structure: demographics

It was not expected that the opening of either line would lead to inflows of higher-educated individuals, it appears to be the opposite case for these areas. The effect is larger for the WIL areas, which is expected to have a bias towards higher-educated people than the SIL areas, although the difference (DID) is not significant. It is plausible that the opening of the WIL attracted an influx of university students/young adults to the area as the popular University of Hong Kong is located in the area and is directly served by the line. Such people do not (yet) own a car but nonetheless count as part of the higher-educated demographic. In the best case, this does not do much to help congestion (population around the area did not change significantly) because car owners are not affected. In a pessimistic case, the influx of people also involve those with even higher disposable income (older adults) who tend to own cars, leading to worse congestion in the long-run. In fact, the mean age in the area during the period increased from 41.2 to 45.1 years, indicating that such an influx could have occurred. The mechanisms of this population movement as well as the movement into the SIL of degree holders is something that should be further investigated.

Concluding remarks and further research

Although many of the relationships that were expected to be observed failed to pass statistical tests of significance, the implication is far from pessimistic in the sense that the conclusion is that limited insights have been developed. On the contrary, it is an important finding that the direct link between the construction of new lines and congestion and the spatial structure of population and demographics appears to be rather weak, and there could be a whole new realm of complexity surrounding the reasons why public transport sometimes fails. The results and the varying degrees to which they conformed with expectations make one thing clear, however – that there is evidence that the provision of mass transit alone in HK with a goal to ensuring the sustainability of the transport system is often highly inadequate. It is perhaps surprising that there is barely any change in congestion (and indirectly traffic flows) in the SIL areas despite population *declining* in the area. The three-car trains of the SIL are rarely packed which naturally lends to the inference that the SIL is far from being used efficiently. This observation is further evidence of the static population in the area during the 2010s. This raises the crucial question of why that is the case, which remains an open question, but it nevertheless demonstrates an inadequacy with the service in tackling HK's problems. On the other hand, the busy WIL fails to address traffic congestion as its commuters are a distinct demographic from the car-driving population in the surrounding area. It is also worth noting that population and congestion remain similar in these areas, yet a significant number of people have been using the lines after their opening. Another possibility is the self-fulfilling prophecy of temporarily reduced congestion increasing the demand for cars (indeed, car ownership is increasing steadily in HK) which causes congestion to rebound to its previous level, which leaves open the question of whether the SAR government's policies and incentives are adequate. It will be interesting to see how the opening of the North Island Line in 2026 at the earliest which runs across the reclaimed land of the northern tip of Hong Kong Island will influence traffic – the road density in the area is relatively poor and the line's opening would be another case of the provision of rapid transit where there is not already a high-capacity road network. This will certainly be a point of great research interest come the next decade.

Of course, the government's main purpose of constructing an extensive network of MTR lines is to cater to the millions of individuals who commute on the system on a daily basis. There is nothing to disparage when it comes to the MTR's speed, accessibility, convenience and reliability. But by relying solely on constructing new roads and rail lines, the failure of the authorities to make material improvements to the situation manifests clearly. Any government has a huge task in running the various aspects of a territory, enforcing law and order and developing roadmaps for the future, and responsibilities extend far beyond transport issues. However, as demonstrated by these findings, it would be an excellent move in the right direction for the government to take a step back to the drawing board to understand the mechanisms of HK's deep-rooted problems more thoroughly.

This notwithstanding, it is also prudent to take note of the limitations of this study, in particular its lack of statistical power. It is plausible that limits on sample sizes and available time frames of certain data have reduced the robustness of the statistical analysis. The indirect approach to measuring congestion using a model with journey times, AADT and road speed limits is theoretically plausible depending on the simplifying assumptions made, but it fails to hit generally accepted significance values. A larger sample size may pave the way for a statistically significant model. It is hoped that more journey time indicators will be made available in the years to come. Overall, the mechanisms of traffic flow and road congestion could be further studied with research dedicated to the topic and a more rigorous mathematical model.

A major limiting factor has been the infrequent demographic data. This is understandable, as census data is costly and time-consuming to obtain. Nonetheless, I appeal to the SAR government to continue to disseminate such information as frequently as possible, to help support research efforts into solving this and many other problems.

This research could have only covered so much within the limits of its official requirements. It has become apparent that the transport issue in Hong Kong involve many complex and nuanced phenomena that require far more detailed models to adequately predict and explain the relationship between mass transit, road traffic and population. Yet it makes a crucial point: authorities in Hong Kong and elsewhere should not rely on simplified assumptions and models in the pursuit of sustainable transport, and other failed projects around the world serve as a reminder of this. This paper sets the direction for which questions to ask from now on and the means to answer them. It is hoped that the answers to the questions left open by this research can thence be sought.

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Appendices

Appendix I – MTR Modified Initial System

Notes: *Argyle, Waterloo and Chater have been renamed Mong Kok, Yau Ma Tei and Central respectively.*

(MTR Corporation, 1978)

Appendix II – small street block planning group divisions

(QGIS, own work)