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**Item title:** Commuter cycling policy in Singapore:  
a farecard data analytics based approach

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# Commuter Cycling Policy in Singapore: A Farecard Data Analytics Based Approach

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**Abstract.** Peak-hour week-day traffic congestion is a common challenge in urban mobility. Promotion of commuter cycling can help in alleviating this problem in many cities. This paper takes a data analytics approach to propose policies for promoting commuter cycling in Singapore. It uses farecard data to assess the commuter cycling potential and develops a data-driven approach to policy making. A spatio-temporal analysis of farecard data helps in finding patterns in the potential demand for first-mile as well as end-to-end cycling. This analysis is used to suggest policies like cycling towns to promote first-mile cycling and cycling regions to enable end-to-end cycling by linking together the cycling towns. Furthermore, an optimization model is developed to make efficient choice of cycling towns and links for a given budget so as to maximize the potential number of commuter cyclists.

**Keywords:** *Commuter cycling policy, farecard analytics, Singapore transportation, urban mobility,*

# 1. Introduction

Peak-time week-day commuting is a key concern in urban mobility. In many cities, an increasing dependence on private cars and motor-bikes for commuting causes severe traffic congestion during peak-hours. Such traffic congestion becomes an economic issue when it reduces productivity and drives away companies to more competitive cities. Furthermore, concerns about how congestion deteriorates the quality of life and environmental sustainability are gaining importance. Most often, public policies focus on improvement of public transport or active discouragement of cars to reduce use of private motorized vehicles for commuting. As a result, in most cities, there is a lack of emphasis and clarity on promoting alternative private modes like cycling for commuting purposes.

Cycling can play an important role in urban mobility because it is an efficient, non-polluting and cheap mode for short distance trips. Apart from encouraging a shift from cars to public transport by providing efficient last-mile connections, commuter cycling can take a significant share of end-to-end short distance trips. Hence, cycling should be promoted as an efficient option for commuting in certain urban contexts. However, there is not enough research on how to assess commuter cycling potential and where to plan for cycling infrastructure in cities (Heinen 2011, McClintock 2002, Pucher, Dill and Handy 2010, P. Rietveld 2001). Besides, there is a paucity of reliable cycling demand data and the planning process is often driven more by passion and less by reason. Furthermore, policies intended to promote cycling in general may end up benefitting recreational cycling without encouraging more commuters to cycle (Heinen 2011, Buehler and Pucher 2012).

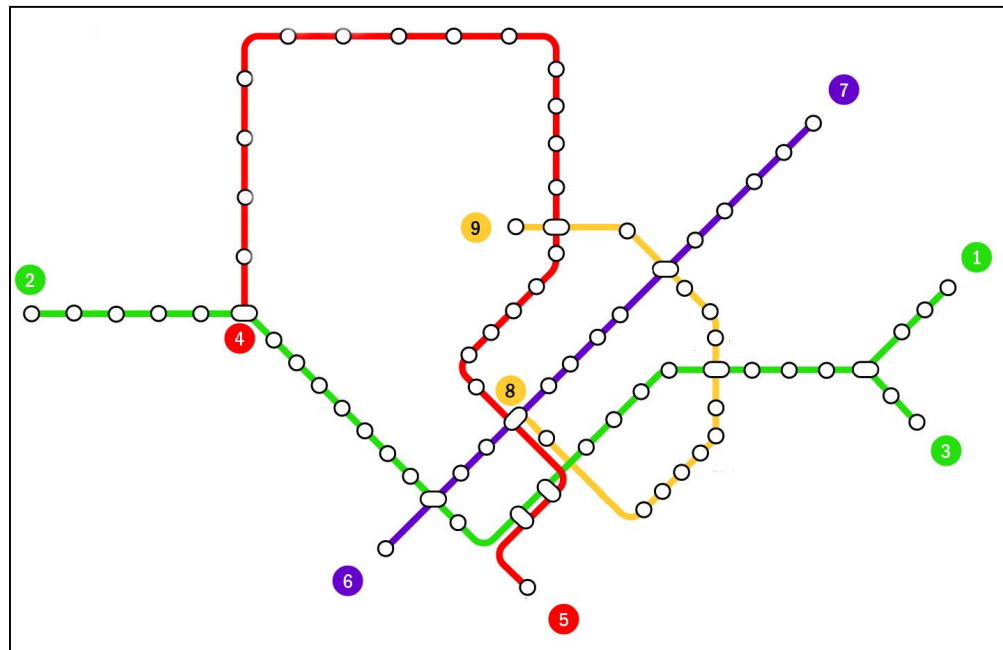
In Singapore, the modal share of commuter cycling is around 1% and is not considered a mainstream option. Besides, there is a lack of comprehensive studies to make policies for cycling (Barter 2008).

This paper tries to address the above mentioned research gaps. First, it surveys the academic literature to understand different types of commuter cycling, its key determinants and the policies that should matter most in the case of Singapore. Second, it assesses the potential demand for commuter cycling in Singapore through the analysis and spatial visualization of farecard data. Third, we propose an optimization-based decision support model to make efficient policy choices for maximizing commuter cyclists. This paper leverages the availability of a rich farecard data-set provided by the Land Transport Authority (LTA) of Singapore. Hence, it also indirectly sheds light on the key information that needs to be captured through farecards in different cities to enable a similar analysis.

## 2. Urban Mobility in Singapore: Role of Commuter Cycling

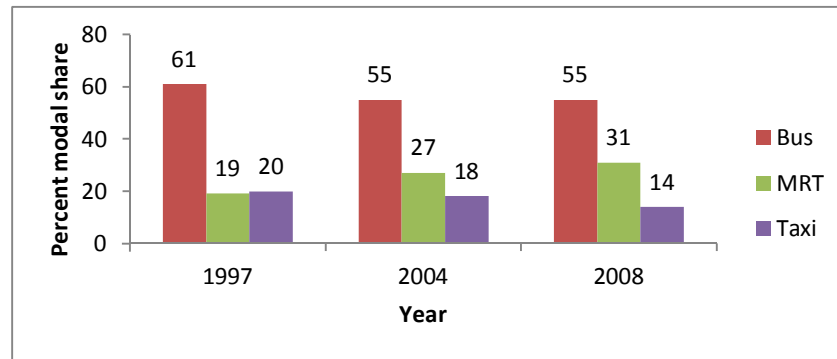
### 2.1 Current Mobility Situation, Policies and Perspective

Singapore has pioneered innovative urban transport policies in electronic road pricing and vehicle quota system, and has an extensive network of rail and bus based public transportation. There are more than 300 bus services and the current Mass Rapid Transit (MRT) network includes 102 stations with 148km of rail-route (LTA 2012). *Fig 1* shows the MRT network as of 2012.



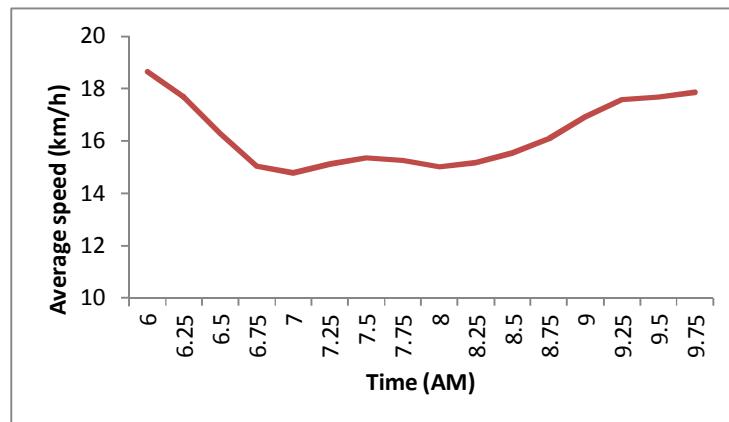
**Fig. 1** MRT network in Singapore (in June 2013)

Despite a good public transport network, Singapore faces a trend of declining public transport share along with an increase in car usage. The modal share of public transport declined from 63% in 1997 to 56% in 2008 (Cheong and Toh 2010). Amongst public transport modes, bus and taxi modal shares have gone down (*Fig 2*) while the MRT share has gone up. It is partly explained by the speed advantage of MRT over buses, especially during peak-hours (*Fig 3*) when average bus speed nosedives. Further, *Fig 4* shows that not only the modal share of buses has gone down but also the average trip length has declined from 5.4 km in 2005 to 4.5 km in 2011 (LTA 2006, LTA 2011, LTA 2012). It suggests that buses are losing popularity for longer commutes and are being used more for shorter distance trips.

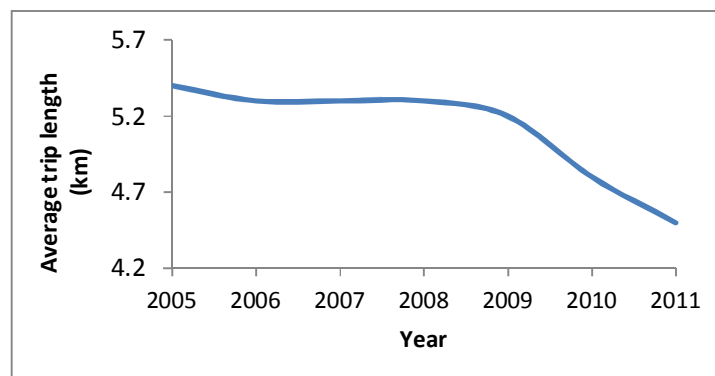


**Fig. 2** Modal share within public transport sector including taxis (Cheong and Toh 2010)

Though increase in MRT's modal share is partly due to its network expansion, its efficiency for longer commutes has also helped it to become a popular mode of public transport. The Household Interview Travel (HIT) Survey (2008) suggests that even people in high-income groups, who are more likely to own cars, frequently use MRT because of its comfort and speed (Cheong and Toh 2010). There is also an increase in use of cars for feeder (first/last mile) trips by more than 50%: from 0.5 million trips in 1997 to 0.78 million trips in 2008 (Cheong and Toh 2010). This trend not only demonstrates increasing acceptance of MRT as an efficient mode for commuting, but also highlights the inadequacy of existing feeder services.



**Fig. 3** Decline in bus speed during morning hours (source: farecard data analysis)



**Fig. 4** Decreasing average bus-trip length (source: LTA annual statistics)

Accessibility of MRT stations emerges as a key criterion for the ridership of mass transits. HIT survey (2008) results show that more than 70% of commuters living within walking distance of transit stations prefer to take the MRT, but this percentage sharply drops to less than 40% at a distance of 2 km. An explanation of this behaviour could be the fact that the first-mile access often consumes disproportionately large amount of time and effort over the whole journey and makes public transits less competitive vis-a-vis car.

Facing these facts, the government of Singapore is investing heavily to expand MRT network to make it mainstay of public transport network. LTA plans to increase the MRT network from the existing 148 km in 2012 to 278 km by 2020. This will make Singapore mass transit network comparable to New York and London in terms of density. In the city centre area, there would be at least one MRT station within five minute walk from any point (Ministry of Transport 2011). That means there should be no need for a feeder service at the work-end of MRT trips to the city area. Besides MRT expansion, Singapore government plans to spend \$1.1 billion over the next 10 years (2012-22) to improve feeder bus services. The target is to decongest feeder services and improve their frequency to 6 minutes on most routes (Shanmugaratnam 2012).

With these key interventions, the land transport master plan (LTMP) 2008 aims at increasing the mode share of public transport from 59 per cent during morning peak hours in 2008 to 70 per cent by 2020. The objective is to make public transport more competitive vis-a-vis car in all respects, especially with respect to total travel times (Ministry of Transport 2012).

While expansion of MRT network would bring more people within walking distance of transit stations and would reduce their travel times, still a large part of population would need to use some other mode for the first-mile. Though investment in improving the feeder bus services would be helpful for the above purpose, it would be costly and loss-making to improve the quality of service substantially without raising the effective fares. Besides, there are inherent issues of reliability of buses with respect to arrival and travel time which are difficult to address (Lee et al 2012). Promotion of commuter cycling could provide an efficient, competitive, low-cost alternative to feeder buses and private cars for the first-mile. It could also alleviate many short distance end-to-end car and public transport commutes (Barter 2008, Heinen, Wee and Maat 2010).

## **2.2 Evaluating Cycling as a Commuting Option in Singapore**

Cycling offers many benefits to problems of urban mobility. Apart from being a clean, cheap and equitable mode of transport for short-distance journeys, cycling can potentially reduce traffic congestion, parking space requirements and roadway costs (McClintock 2002, Heinen et al 2010). It is one of the most sustainable and efficient transportation modes for trips of distance up to around 5 km (Midgley 2011, Buehler 2010). Consequently, it has a place in a policy maker's tool-kit of urban mobility solutions, especially for short distance trips. Safety, comfort, convenience and acceptability/status of cycle as a mainstream transport mode are the key drivers of commuter cycling. Except for natural barriers, public policies may address and improve

many of these factors (Buehler 2010, Pucher and Buehler 2008, Barter 2008). However, for longer trips cycling becomes uncomfortable and inefficient. Besides, changing the trip length distribution requires long-term urban planning policies. Hence, practically, short trip length is a major pre-requisite to encourage commuters to cycle (Ellison and Greaves 2011, Heinen, Wee and Maat 2010, Brunsing 1997).

Adverse weather and topography can make cycling challenging. In Singapore, during morning commuting hours, the prevalent temperature rarely exceeds 27C, though humidity often exceeds 80%. Many research studies suggest that these are reasonably good conditions for cycling. Moreover, there are studies showing that regular cycle commuters are not very sensitive to temperature changes unless these are rather extreme (Heinen et al 2010, Nankervis 1999, Moreno Miranda and Nosal 2011). Rainfall affects cycling levels temporarily but is not a major constraint at aggregate level, as evidence from many European cities with heavy rainfall suggests (Buehler 2010, Heinen et al 2010). While data also suggests that cycling decreases when gradient exceeds 4% (Heinen et al 2010), it is not a deterrent in Singapore as it has a largely flat terrain.

Effective integration of cycling with transit may increase the catchment area and ridership of transits. It can also improve the overall efficiency of public transport by reducing the need for feeder buses (Krzek and Stonebraker 2010, Martens 2004). Many commuters can also cut down their total travel times by cycling to MRT stations rather than taking feeder buses (Ellison and Greaves 2011, Keijer and Rietveld 2000). Hence, in Singapore, the potential for commuter cycling is likely to grow with the expansion in MRT network requiring more short-distance feeder trips, though some existing feeder trips may also be obviated due to the expansion of MRT network.

In Singapore, a low public image of commuter cyclists could be a challenge to begin with (Barter 2008). However, with sustained improvement in infrastructure and with subsequent increase in usage of cycling by well-off commuters, this is likely to change overtime.

The above discussion shows that there are no major natural constraints to commuter cycling in Singapore, and public policies can encourage commuters to switch to cycle mainly for the short-distance trips, preferably up to 3 km, for the first-mile (home-transit) connections (Heinen, Wee and Maat 2010, Keijer and Rietveld 2000, Koh, et al. 2011). These short-distance trips could either be the first-mile trips as a part of a public transit journey or could be the end-to-end trips. Further, the literature shows that commuters may cycle relatively longer distances, up to 5km, for the end-to-end trips compared to the first-mile trips (Pucher and Buehler 2008).

### **2.3 Current Status of Cycling in Singapore**

Though current cycling levels in Singapore are only around 1% of work-trips, government agencies recognise the increasing role of cycling as an alternative option for short-distance trips to MRT stations and transport hubs (Ministry of Transport 2012, Barter 2008). As a part of a national cycling plan, the LTA rolled out an intra-town cycling programme in 2009. It involved the construction of more than 45km of dedicated off-road cycling tracks in five Housing Development Board (HDB) towns-

Tampines, Yishun, Sembawang, Pasir Ris and Taman Jurong- by 2014. Two more towns - Bedok and Changi Simei – have been added to the list besides a plan to develop more than 16km of cycling paths in the Marina Bay area by 2014 (LTA 2012). These cycling paths would link the residential areas to transport nodes and local amenities . Demand and community support for cycling are the main criteria for the selection of cycling towns (LTA 2010). LTA has also planned the addition of more than 2500 bicycle parking racks at MRT stations and bus interchanges by 2013 (Ministry of Transport 2012, LTA 2012).

In Singapore, there also exist more than 200 km of park connectors, which is the network of off-road pan-island cycling paths joining various parks (National Parks 2012). There are plans to increase it to 300km by 2015 (Koh, et al. 2011). Though, it was built primarily for recreational cycling, it can be leveraged to create opportunities for commuter cycling.

### **3. Methodology and Data Description**

Literature survey suggests that trip distance is the key criterion which determines whether a trip is bike-able or not. Hence, we consider the assessment of short-distance commuting trips a good indicator of the potential trips that can be shifted to bicycle.

We consider two types of trips which can be shifted to cycling: the first mile and the end-to-end trips. With Singapore's MRT system, there exist a large number of feeder (first-mile) short-distance trips by bus and car to MRT stations. These trips can be completed more efficiently by cycling. Based on a literature review, we find out that most commuters prefer to cycle for the first-mile up to 3 km. Hence, we take 3 km as the cut-off trip distance to assess first-mile cycling potential. For the end-to-end trips, based on the research literature, we take relatively higher value of 5 km as the maximum distance. Through farecard analysis, we find spatial distribution of first-mile and end-to-end trips centered around MRT stations.

We treat first-mile and end-to-end trips differently, as the policies required, as well as the impact on the transport system, is different for both in many respects. While first-mile trips require cycling infrastructure and facilities centered around MRT stations, end-to-end trips need network of cycling infrastructure along the whole route, as well as cycling facilities at destinations (offices, factories, business district, schools etc.). While cycling for the first-mile helps in increasing the efficiency and ridership of public transport, end-to-end cycling can reduce short-distance car, bus, as well as MRT trips. The potential of cycling to school is assessed separately as policies need to stress more upon safety, training and communication with parents.

Finally, we develop an optimization based decision support model to make an efficient choice of policies/projects to maximise potential cyclists for a given investment level. Inputs to the model include cycling demand numbers, cost estimates of cycling infrastructure, percentage switch to cycling from different modes for first-mile and end-to-end trips and investment levels.



### 3.1 Data Description, Cleaning and Processing

To assess commuter cycling potential in Singapore, we need information about trips made during peak-hours through different modes. We are privileged to have a unique farecard dataset originating from Singapore's public transportation network. This fare card, called EZ-link, was introduced in 2003 (EZ-link 2012). These farecards are widely used for seamless distance-based payment across buses and MRT, and cover more than 96% of all public transport trips (Prakasam 2009). This farecard data provides detailed trip information including trip origin and destination, trip start and end timings, trip lengths, and details of transfers across public transportation modes. Singapore is one of the few cities that capture such comprehensive data about public transport usage, especially the destination data, which opens up a myriad of possibilities for using analytics. Data for car trips (including private car, taxis, etc.) is not readily available; however, we can assume that the Singapore public transport flows represent the global travelling patterns. Consequently, we use LTA's farecard data to approximate the number of trips which can be converted to cycling from different modes.

The farecard data that we shall use corresponds to five consecutive weekdays (from 11<sup>th</sup> April 2011, Monday to 15<sup>th</sup> April 2011, Friday). Since there were no school or office holidays during this period, these data are a good representation of typical working day peak flows. We consider a time frame from 6.30AM to 9AM for our analysis as this interval not only captures the morning peak hour traffic but weather conditions are also more suitable for cycling.

The database stores all public transportation trips made during the day, including bus, MRT and LRT. By definition, one journey of a passenger may compose of several trips. Each trip is identified by the unique card number of the passenger, passenger type (child, adult, senior), origin, destination, service number (for bus), tap-in time, duration, trip distance as well as the sequence number of the trip in the journey. From the unique card number, we can filter all the trips made by a specific passenger, and using the tap-in time and the sequence number, we can build his whole itinerary. The sequence number allows us identify the first and last mile of the journey, with the distance directly available through the database.

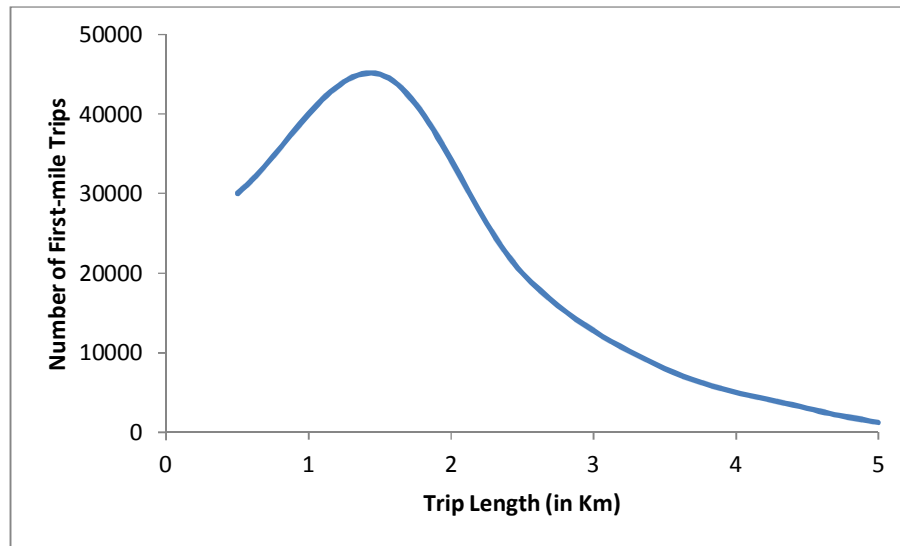
The passengers may create false entries by several ways: forgetting to tap out at exit (resulting in missing values in duration and trip distance), tap-in and out at the same stop (resulting in distance of 0). We remove all these bad entries from the database, along with other entries made by the same card number to avoid noise. All manipulation of the data and statistical analysis are done using the language R.

## 4. Data Analysis and Key Observations

### 4.1 First and Last Mile Trips

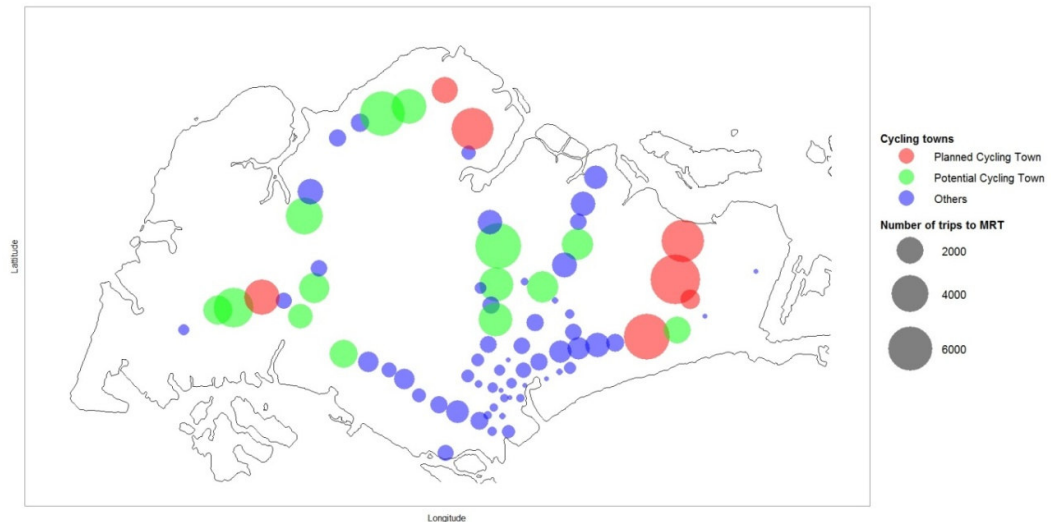
More than 120,000 commuters use feeder buses daily to take a first-mile trip (mainly home to MRT station) for a subsequent MRT trip. *Fig 5* shows the distance distribution of first mile trips up to 5km distance. A large percentage of these first mile trips is less than 3km long which is a good distance to encourage switch to cycling. Most of these trips are made by adults with students accounting for less than 5 percent of all first-mile trips. On the other hand, less than 7,500 commuters take a last-mile trip (MRT station to

work-place) by feeder bus after completing their MRT trip. It suggests that last-mile (work-end) feeder trips are small in number compared to the first-mile (home-end) feeder trips. Hence we shall not pay much attention to last-mile (work-end) trips in our analysis.

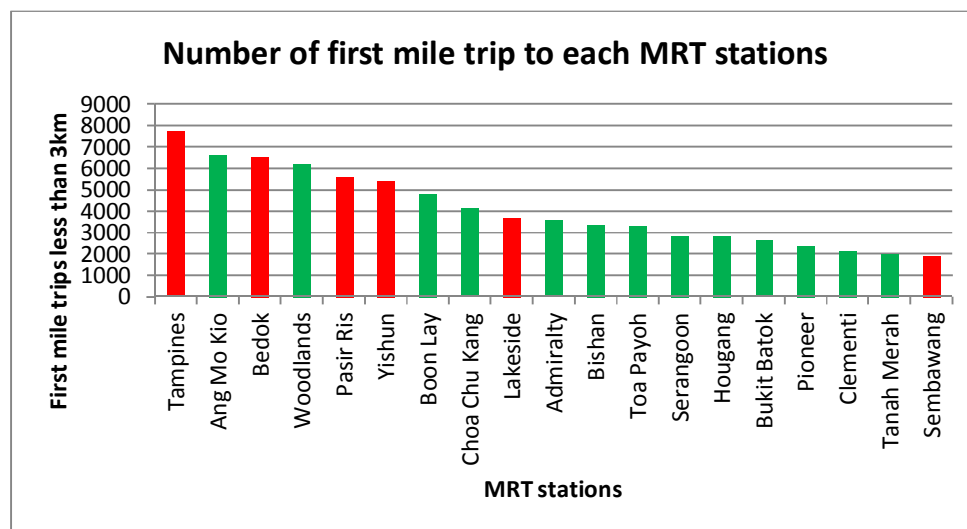


**Fig. 5** Distance distribution of the first mile trips (6.30AM to 9AM)

*Fig 6* shows the spatial distribution of these short distance (less than 3km) first mile trips to MRT stations with the area of each bubble proportional to the number of these first mile trips. We use red to represent the seven planned cycling towns under the LTA cycling plan, and green to represent the potential cycling towns based on the number of first mile trips. Despite having more than 100 MRT stations, most short distance first mile trips are concentrated in suburban, residential towns such as Tampines, Ang Mo Kio and Bedok. Consequentially, 19 MRT stations, as shown in *Fig 7*, can cover up to 71% of all these first mile trips. This spatial distribution supports the development of a cycling infrastructure in the neighborhood of these stations.



**Fig. 6** Spatial distribution of first mile trips to MRT stations (6.30AM to 9AM)



**Fig. 7** Number of the first mile trips to MRT stations (LTA's planned cycling towns in red)

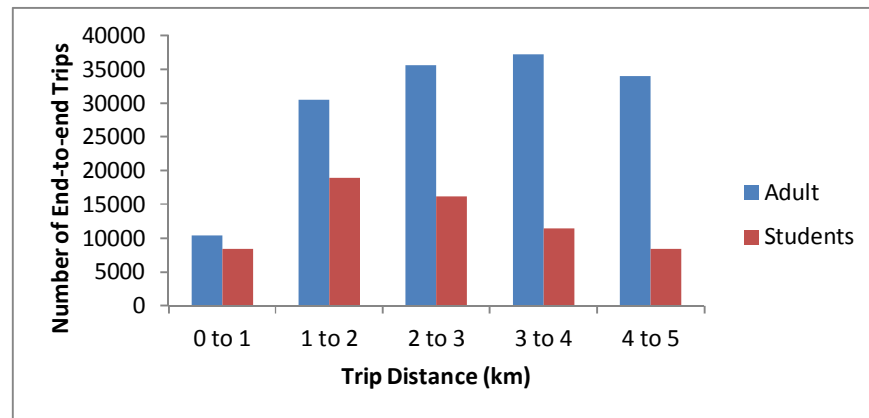
There is also a large number of first-mile trips by car (drop-offs). Though the distance and spatial distribution of these car trips is not available, we can assume it to be similar to feeder bus trips. HIT survey (2008) estimates number of service trips (drop-off and pick-up to public transport) at 775,000 daily. Assuming that 30% of these service trips take place during morning (6.30AM – 9AM) hours and 50% of drop-offs occur at MRT stations, we estimate car based first-mile trips as 116,000 which is almost equal to bus based first-mile trips.

## 4.2 End-to-end Trips

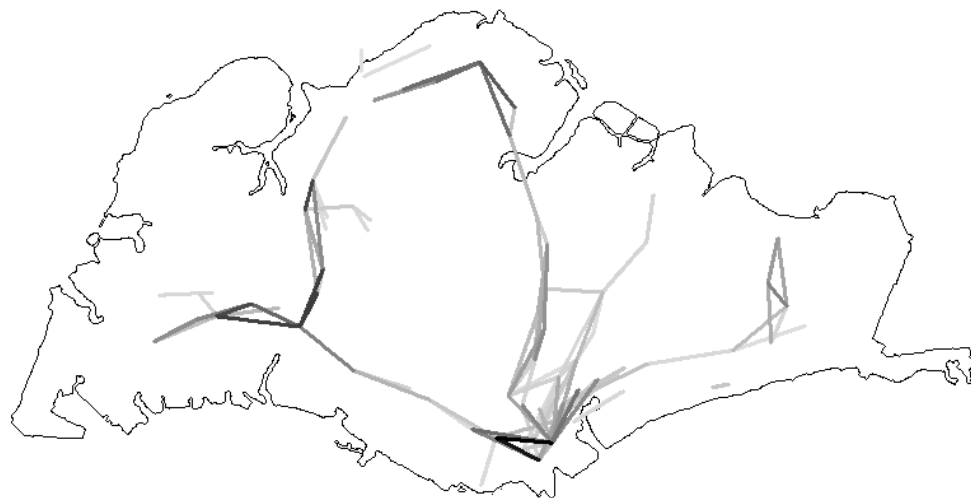
A high percentage of morning commuting journeys are less than 5km in distance: around 25% of all morning public transport commuters undertake an end-to-end short-distance (less than 5 km) journey, of which 58% are adult (not including senior citizens),

and 28% are student/child. *Fig 8* shows that around 70% of the students' trips are of less than 3km length. However, the origins and destinations (OD pairs as approximated by MRT and bus stations) for most of the journeys are dispersed geographically over the whole island. In *Fig 9*, we plot the links representing the OD pairs with at least 100 trips with darker links for heavier flows, and most of these pairs connect MRT stations. It is, however, difficult to depict spatially other short distance, low volume bus flows on account of a large number of bus stops, each of which is a unique origin as well as destination. From *Fig 9*, we can see that there are heavy short distance flows to the Central Business District stations like City Hall and Raffles Place. Furthermore, there are also significant flows in the west (Jurong, Boon Lay) and the north (Woodlands) regions. These flows suggest a significant potential for end-to-end cycling along these links.

Further we assume that end-to-end trips by car also have similar distance and spatial distribution. As MRT modal-share is around 20% of all trips (public plus private), the end-to-end short-distance flows, as shown in our analysis, represent only 20% of all short-distance end-to-end flows.



**Fig. 8** Number of short-distance end-to-end trips (6.30AM to 9AM)



**Fig. 9** Spatial distribution of short distance end-to-end trips (darker the line, heavier the flows)

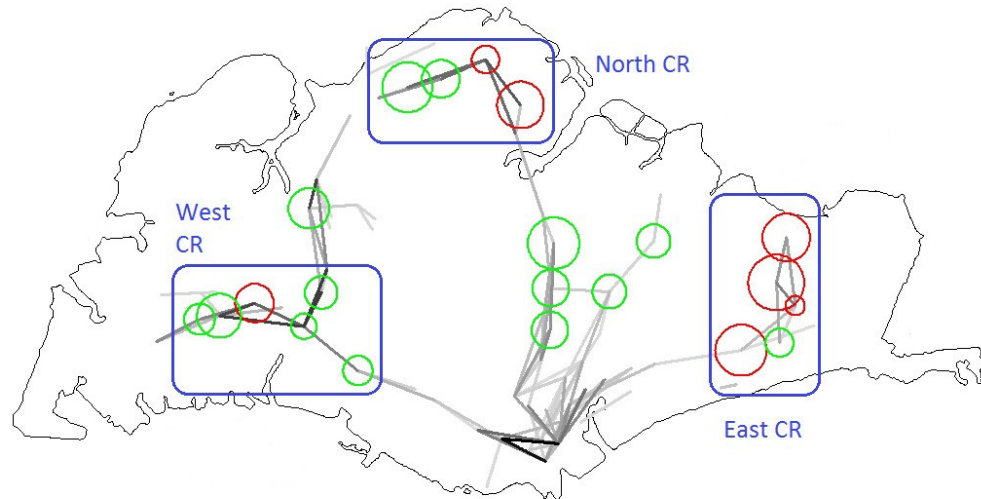
As the number of students taking short end-to-end trips is significant, we also track the OD pairs for students separately. However, we consider only OD pairs of less than 3km distance here, which is more suitable for cycling by kids. We consolidate the OD pairs by the destinations to identify hot spots with large number of inward journeys. We find that the towns like Choa Chu Kang, Lakeside and Tampines, have a large number of end-to-end short-distance school trips, most of which have secondary schools, junior college or ITE as their destinations. These trips can be efficiently shifted to cycling.

## **5. Policy Recommendations and Decision Support Model**

### **5.1 Policy Recommendations**

From the analysis in the last section, there are many insights we can draw upon to propose commuter cycling policies. The first recommendation is about the promotion of cycling towns to realize the potential of first mile cycling. LTA has already selected seven cycling towns for development. From *Fig 7*, we can confirm that the potential for first mile bicycle trips is substantial in six of these towns (except Changi-Simei), especially in Tampines, Bedok, Pasir Ris and Yishun which have a large number of first-mile trips. Besides, based on first-mile demand analysis, we suggest that additional towns like Woodlands, Ang Mo Kio and Boon Lay could be developed into cycling towns in future. Apart from the potential demand, LTA should consider the feasibility and cost aspects of different cycling towns to implement intra-town cycling.

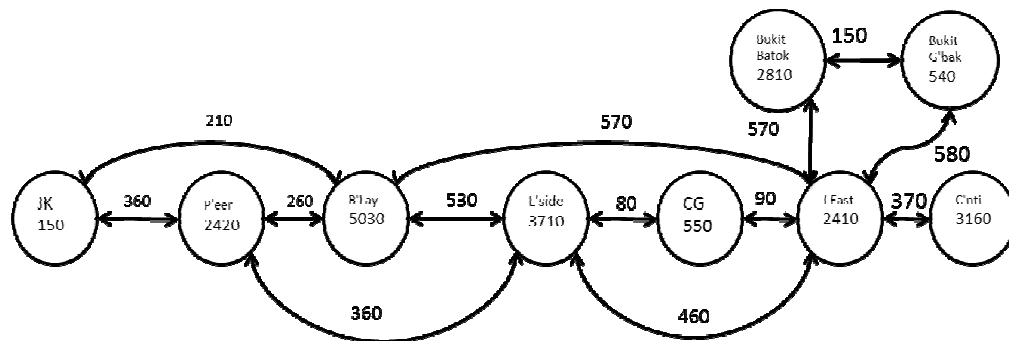
As a second recommendation, we propose the planning of cycling regions to promote end-to-end commuter cycling. Since end-to-end cycling requires not only the integrity of cycling routes but also good cycling infrastructure and facilities at both ends, adjoining cycling towns with significant inter-town flows can be linked through cycling tracks or cycling lanes in order to promote inter-town cycling. From *Fig 10*, we can identify three possible cycling regions: East, North and West cycling regions. Anchored with LTA's planned cycling towns, these regions could be expanded gradually by developing the potential cycling towns and inter-town link networks. We depict the West cycling region as an illustration in *Fig 11* with nodes representing the MRT stations. The number inside each node is the first mile demand to the MRT station, while the links depict the end-to-end flows coupled with the corresponding demand.



**Fig. 10** Proposed cycling regions(CR) on Singapore map

Development of cycling regions can be facilitated by the park connector network. More specifically, the east and north cycling regions can take advantage of the existing eastern coastal loop and the northern explorer loop respectively as shown in *Fig 7*. By providing connections between cycling towns, cycling regions may serve a larger population and a richer variety of trips than the development of cycling towns alone. However, since public funds are limited, all possible cycling towns and links cannot be picked up simultaneously. Hence, in the next section, we propose a decision support model to make the most efficient selection of cycling towns and links.

The central business district (CBD), the area with heavy flows in the south-central region of *Fig 10*, is also the destination for a large number of short-distance commuter flows. However, it may be difficult to develop cycling infrastructure along the busy roads to CBD due to space constraint. Hence, we have not identified it as a potential cycling region despite heavy flows.



**Fig. 11** West cycling region's commuter cycling flows

Finally, we recommend the concept of school cycling enclaves in areas where a high proportion of end-to-end cyclists are students. From the OD analysis of students in the previous section, we find that Choa Chu Kang can emerge as a future school cycling enclave. With a relatively high concentration of schools, especially secondary schools

and junior college/ITE, Choa Chu Kang generates high flow of students in its neighborhood. These flows can be shifted to cycling easily if higher standards of safety are ensured. Therefore, school-centric cycling enclaves would require the development of safety focused cycling infrastructure around schools and deeper community involvement to encourage parents to support cycling by students.

Apart from the policies related with infrastructure, research literature points out the importance of other soft policies such as public education, law enforcement and work-place policies in encouraging modal switch to cycling. All these policies should be implemented in an efficient, coordinated manner with active community involvement. However this paper does not cover these aspects in detail.

## 5.2 Decision Support Model

In this section, we propose an optimization model to support the policy makers in making better choice of cycling towns and cycling regions as suggested in the previous section. While choice of cycling towns apparently looks straightforward with policy makers picking MRT stations in decreasing order of first mile demand, the integration within cycling regions introduces a higher level of complexity. On one hand, this complexity arises from a large number of end-to-end demands which are sparsely distributed over the island. On the other hand, each cycling link can serve multiple end-to-end demands at the same time. For example, considering three cycling towns in a straight line A-B-C : link A-B serves not only demand from A to B and vice versa, but also demand between A and C. This results in a higher complexity of the decision process, thus the need for our decision support model.

In this model, we assume that the policy maker will build cycling towns centered at MRT stations. This assumption is reasonable for the case of Singapore and is further reinforced by LTA's choice of current cycling towns in the neighborhood of MRT stations. Development of cycling infrastructure around MRT stations better serves the purpose of providing first and last mile transportation.

Furthermore, we make the assumption that each cycling link has to connect two cycling towns to ensure accessibility as well as smoothness of cycling trips for the end-to-end demand. Indeed, if the cycling town is not developed, the cyclists may have difficulties at the first or the last mile, which reduces the attractiveness of the cycling option. In our model, a cycling link can refer to a cycling track or a cycling lane depending on engineering considerations.

Let  $G = (N, E)$  be a graph representing the MRT stations in Singapore, with  $N$  be the set of MRT stations and  $E$  be the set of edges connecting two adjacent stations on the MRT line. At each MRT station  $i \in N$ , there is a cycling first mile demand  $d_i$ . The set  $C$  contains all short distance end to end demand, and each demand  $c \in C$  has an origin  $o(c) \in N$ , a destination  $d(c) \in N$  and with cycling demand of  $a_c$ . For a time horizon  $T$ , the benefit of serving one cyclist is  $b$ . The cost of building a cycling town at MRT station  $i$  is  $h_i$ , and the cost per km to build a cycling track connecting station  $i$  and  $j$  is  $k_{ij}$ .

We denote  $CT \subseteq N$  as the set of MRT stations with existing cycling town, and  $CL \subseteq E$  be the set of existing cycling links. The cost for existing cycling towns and existing cycling links are taken as zero.

The variables are denoted as follows:

$$x_i = \begin{cases} 1, & \text{if a cycling town is to be developed at MRT station } i \\ 0, & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if a path is to be built to connect two stations } i \text{ and } j \\ 0, & \text{otherwise} \end{cases}$$

$$z^c = \begin{cases} 1, & \text{if demand } c \text{ is satisfied} \\ 0, & \text{otherwise} \end{cases}$$

$$f_{ij}^c = \begin{cases} 1, & \text{if demand } c \text{ flows from station } i \text{ to station } j \\ 0, & \text{otherwise} \end{cases}$$

The optimization model with the objective of maximizing potential net benefits is:

$$\max b \left( \sum_{i \in N} d_i x_i + \sum_{c \in C} a_c z^c \right) - \sum_{i \in N} h_i x_i - \sum_{(i,j) \in E} k_{ij} y_{ij} \quad (P1)$$

Subject to:

$$\sum_{(i,j) \in E} f_{ij}^c - \sum_{(j,i) \in E} f_{ji}^c = \begin{cases} z^c, & o(c) = i \\ -z^c, & d(c) = i \\ 0, & \text{otherwise} \end{cases} \quad \forall c \in C, \forall i \in N \quad (1.1)$$

$$y_{ij} \leq x_i \quad \forall (i,j) \in E \quad (1.2)$$

$$y_{ij} \leq x_j \quad \forall (i,j) \in E \quad (1.3)$$

$$f_{ij}^c \leq y_{ij} \quad \forall c \in C, \forall (i,j) \quad (1.4)$$

$$x_i = 1 \quad \forall i \in CT \quad (1.5)$$

$$y_{ij} = 1 \quad \forall (i,j) \in CL \quad (1.6)$$

$$y_{ij} \in \{0,1\} \quad \forall (i,j) \in E \quad (1.7)$$

$$f_{ij}^c \in \{0,1\} \quad \forall c \in C, \forall (i,j) \quad (1.8)$$

$$x_i \in \{0,1\} \quad \forall i \in N \quad (1.9)$$

$$z^c \in \{0,1\} \quad \forall c \in C \quad (1.10)$$

The objective of (P1) is to maximize the net benefit of the policy. Constraint (1.1) is a flow conservation constraint, which ensures that if the demand  $c$  is satisfied, there will



be a possible flow from the origin to the destination of the demand. Constraints (1.2) and (1.3) ensure that the cycling paths connect two cycling towns. Constraint (1.4) forces the flow to be on cycling paths. Constraints (1.5) and (1.6) capture the existing cycling towns and cycling paths.

However, in real life, there are uncertainties as well as inaccuracies in the benefit calculations, especially in context of commuter cycling as it involves monetization of externalities related with congestion, air pollution and health, besides estimation of direct savings and valuation of travel time savings. Any projection of these benefits would vary depending on the choice of the methodology and assumptions about local circumstances. Besides, policy decisions related with transport infrastructure have long-term behavioral as well as environmental implications which cannot be captured in a limited time horizon. Hence, we propose an alternative simple approach to policy-making based on the demand maximization where the policy maker may want to maximize the number of cyclists within a total budget of  $M_B$ .

$$\max \sum_{i \in N} d_i x_i + \sum_{c \in C} a_c z^c \quad (P2)$$

Subject to:

Constraints (1.1) to (1.10)

$$\sum_{i \in N} h_i x_i + \sum_{(i,j) \in E} k_{ij} y_{ij} \leq M_B \quad (2.1)$$

In this model, the objective is to maximize the cycling demand which can be satisfied. The additional constraint (2.1) gives the restriction on the budget. In cases where policy-makers may want to constrain the number of cycling towns  $M_{CT}$ , and the number of cycling links  $M_{CL}$  to be developed, we may replace constraint (2.1) by the following two constraints:

$$\sum_{i \in N, i \notin CT} x_i \leq M_{CT}$$

$$\sum_{(i,j) \in E, (i,j) \notin CL} y_{ij} \leq M_{CL}$$

Both models (P1) and (P2) are binary linear programming problems, which can be solved using commercial solvers such as CPLEX or Gurobi.

### 5.2.1 Experimental Results

Model (P2) requires data concerning cycling demand, the cost of developing cycling towns, the cost of building cycling paths and the budget available. Although not all of

this data is available for Singapore, it can be approximated from the literature or from historical data.

Our first approximation is for the percentage of commuters switching to cycling from different modes. This percentage is used to calculate the first mile and the end to end cycling demand. *Table 1* summarizes the modal share of commuter cycling in different cities. In good cycling towns, the overall commuter cycling modal share is generally more than 20%. Unfortunately, there is no data available exclusively for the end-to-end cycling modal share. In this model, we use a conservative approximation of 10% of first mile and end-to-end short distance commuters switching to cycling.

Regarding the cost, it can be approximated from LTA's report (LTA 2012) about expenditure on cycling towns. LTA plans to spend \$43 million for the first 5 cycling towns, consisting of building 30km of new cycling tracks. As a result, the cost of developing a cycling town is estimated at \$10 million, and the cost of building a cycling link is \$0.5 million per km. The unit distance cost of the cycling link is below the average cost taken from the LTA's report because the cycling infrastructure available in cycling town reduces the requirements of new constructions for cycling links.

**Table 1** Modal share of commuter cycling in different cities

City name	Overall Commuter cycling modal share	First-mile cycling modal share (% of all transit trips)
Amsterdam	34% (Buehler 2010)	
Copenhagen	36% (Pucher and Buehler 2008)	25% (Martens 2004)
Denmark (avg)	35% (Pucher and Buehler 2008)	N.A.
Netherlands (avg)	32% (Pucher and Buehler 2008)	30% (Martens 2004)
Germany (avg)	28% (Pucher and Buehler 2008)	N.A.
Tokyo	N.A.	20% (Andrade and Kagaya 2011)
Osaka	N.A.	25% (Andrade and Kagaya 2011)
Nagoya	N.A.	35% (Andrade and Kagaya 2011)

N.A. means not available

For sensitivity analysis, we compare the solutions with different levels of available annual budget, which are described in *Table 2*. The nominal budget available is taken as \$100 million based on per capita annual expenditure of €13 on cycling related infrastructure in Amsterdam as Dutch cities are considered good examples of commuter cycling (Pucher et al 2010). The low and high scenarios are taken as  $\pm 30\%$  of the nominal value.

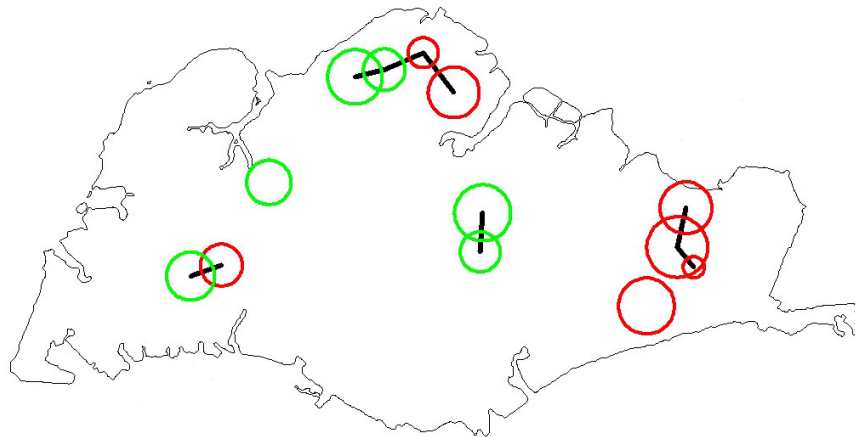
**Table 2** Budget values for three scenarios

	Low	Nominal	High
Budget	\$70 Millions	\$100 Millions	\$130 Millions

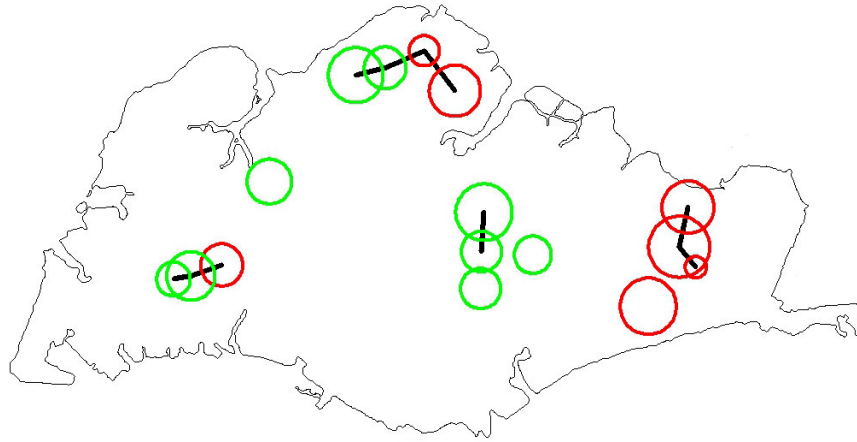
As an initial condition, the seven cycling towns from the current LTA plan are considered as existing cycling towns in the model. The solutions are shown in *Fig 12 to 14* with circles showing the cycling towns (red circles depicting planned cycling towns) and black lines showing the cycling links.

From this result, the northern cycling region is fully justified for all three scenarios of the available budget; this strongly supports the construction and development of cycling towns and cycling links in the area. On the other hand, the western and eastern cycling regions can only be partially implemented despite the strong inter-flows between cycling towns as shown in *Fig 10*. The full implementation of these two cycling towns would require a higher budget to make it feasible. Based on the potential demand, some cycling towns and links close to CBD are also picked up as shown in *Fig 12 to 14*. However, its implementation would be relatively difficult as it involves development of cycling infrastructure in densely built up area.

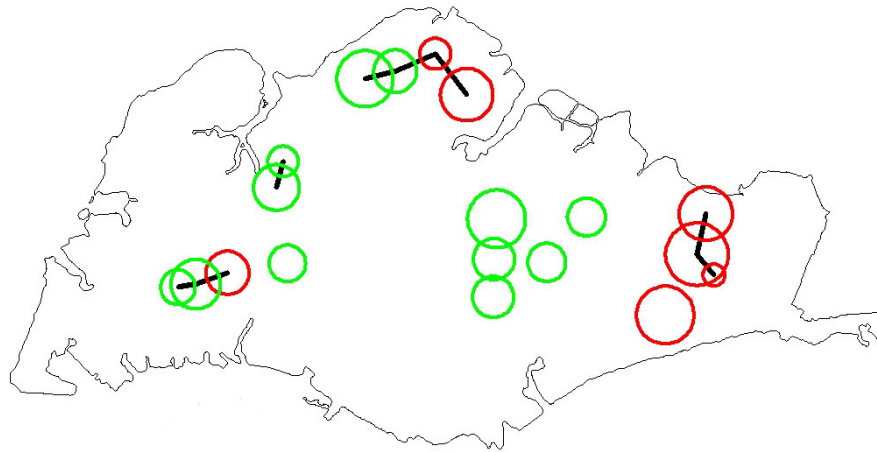
With the increase in the budget, there is a tendency to invest more in cycling towns. This may be due to the high first-mile demand to the MRT stations. There is also a consistency in the cycling towns chosen for development throughout the three scenarios, though there is a minor inconsistency with one cycling link. This fact suggests that the planner can use this model for incremental implementation as well.



**Fig. 12** Solution of the optimization model with budget \$70 million



**Fig. 13** Solution of the optimization model with budget \$100 million



**Fig. 14** Solution of the optimization model with budget \$130 million

This decision support model is a practical tool for city wide planning of cycling infrastructure for a given budget constraint. Reliability of the model can be improved through better estimates of cycling infrastructure cost and modal switch percentages for different towns and links. More specifically, the infrastructure cost shall be different depending on the urban form of each town and choice of infrastructure design. The cycling demand can be estimated better by taking into account the private vehicle flows, or even the walking patterns. Furthermore, the percentage of commuters who switch to cycling from different modes would vary depending on local circumstances. These are open questions for future research.

## 6. Conclusions

Commuter cycling can play a significant role in alleviating morning peak-time congestion in many cities. Through fare card data analysis, this paper confirms good potential of commuter cycling for the first-mile as well as end-to-end trips in Singapore. Commuter cycling can encourage use of MRT by providing an efficient option for first-mile (home-

end) trips. It can provide an efficient alternative to feeder buses besides substituting many first-mile trips by car. Many short-distance end-to-end trips can also be travelled by bicycles.

In this paper, we give three main policy recommendations to promote commuter cycling in Singapore. These recommendations include suggestion of more cycling towns, developing cycling regions and advocating the concept of school cycling enclaves. As these policies are based on better understanding and visualization of the demand through farecard data analytics, the policy-making process becomes more objective and transparent.

We also propose an optimization model as a decision support tool to make efficient choice of cycling towns and links for a given budget constraint. As suggested in the paper, it can be a useful tool for efficient policy making.

The farecard in Singapore captures information about the origin, destination as well as transfers involved in a public transport journey. Availability of this data is a pre-requisite to apply the proposed methodology to assess commuter cycling demand. Hence other cities should also collect this information through their farecards to enable a similar analysis.

**Acknowledgements:** The authors acknowledge the financial support of the Singapore-MIT alliance for research and technology (SMART) for this work. The authors also thank Professor Amedeo R. Odoni, MIT and professor Paul Barter, NUS, for their valuable advice.

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