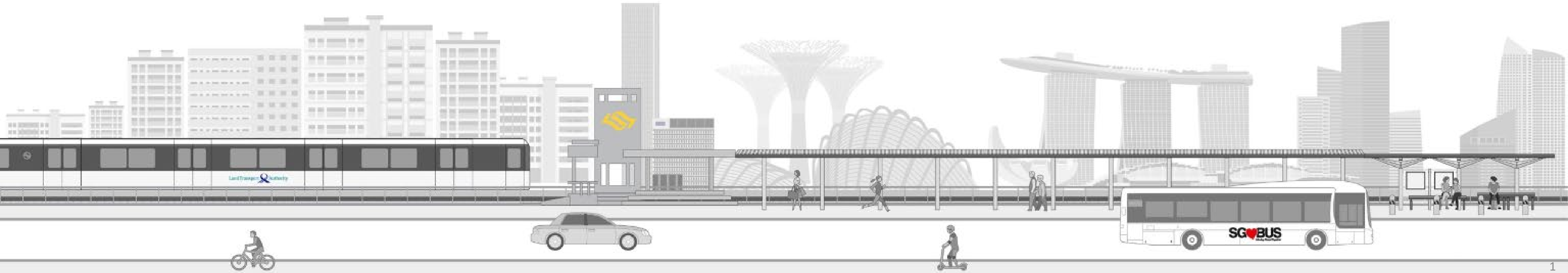
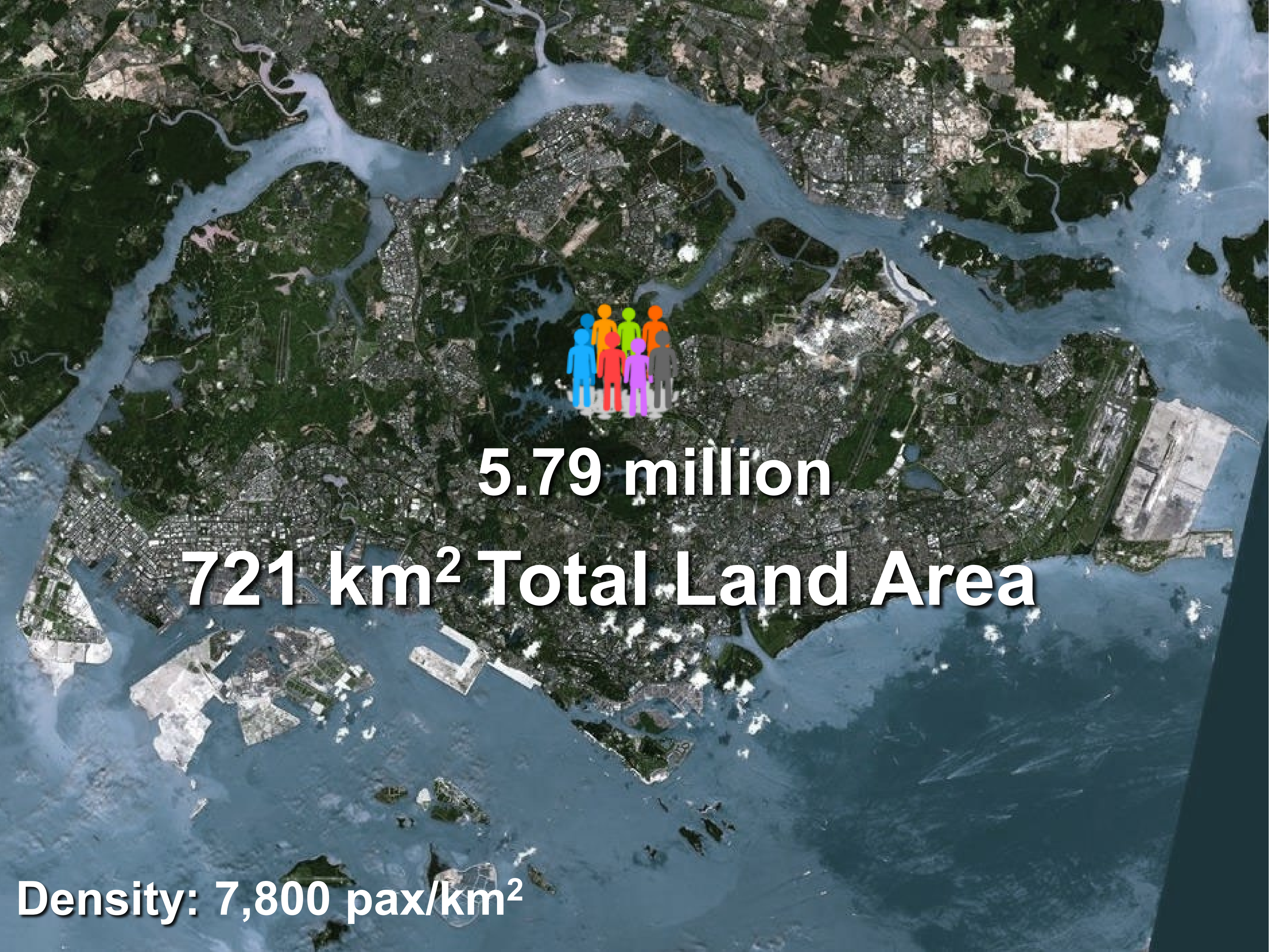
Land Transport Authority
We Keep Your World Moving

# Dynamic Bus Routing: The Role of High-Capacity On-Demand Ridesharing in a Population-Dense Urban Environment

Land Transport Authority, Singapore





5.79 million

$721\ km^2$ Total Land Area

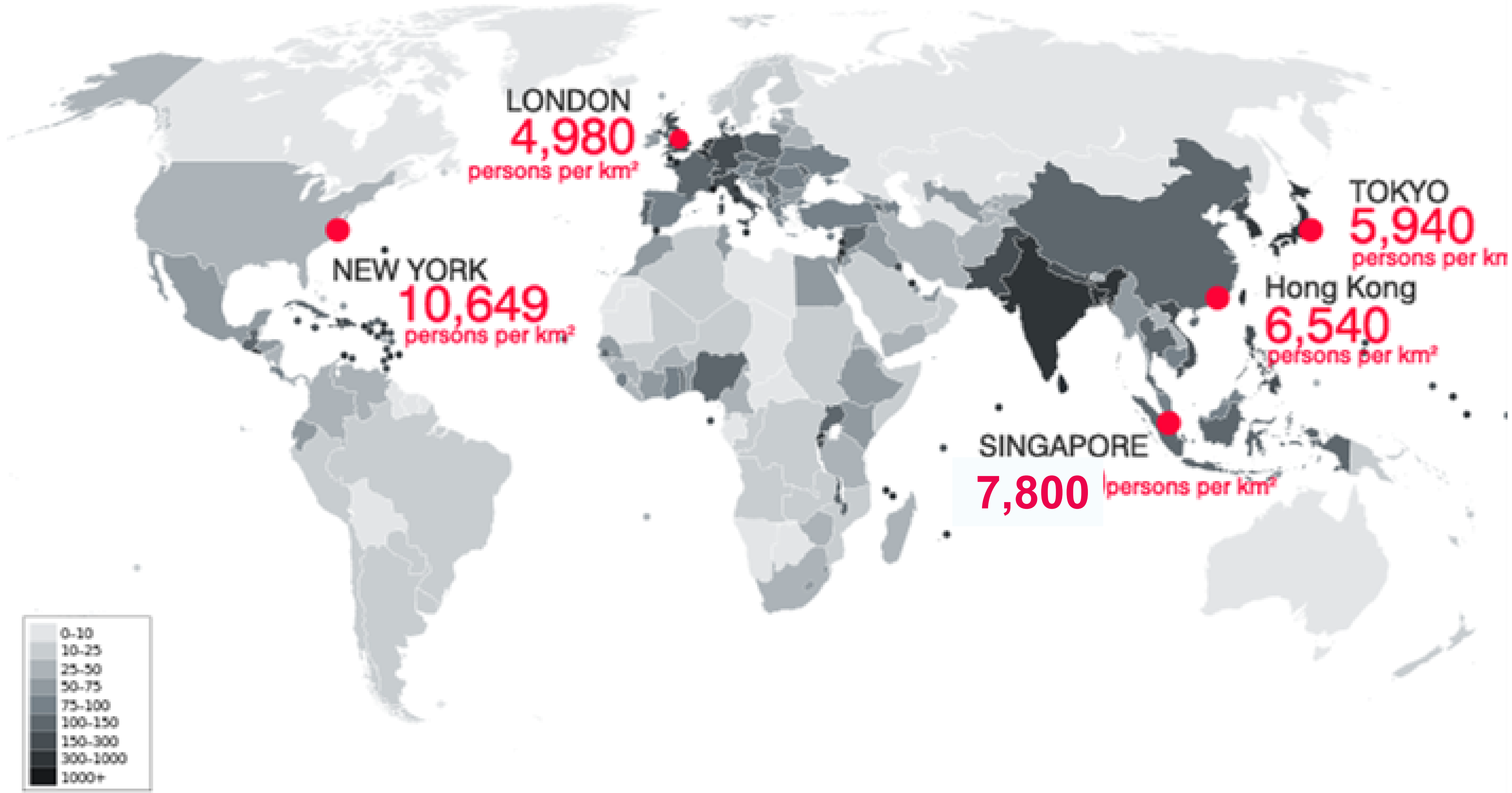
Density: 7,800 pax/$km^2$

London (2X)

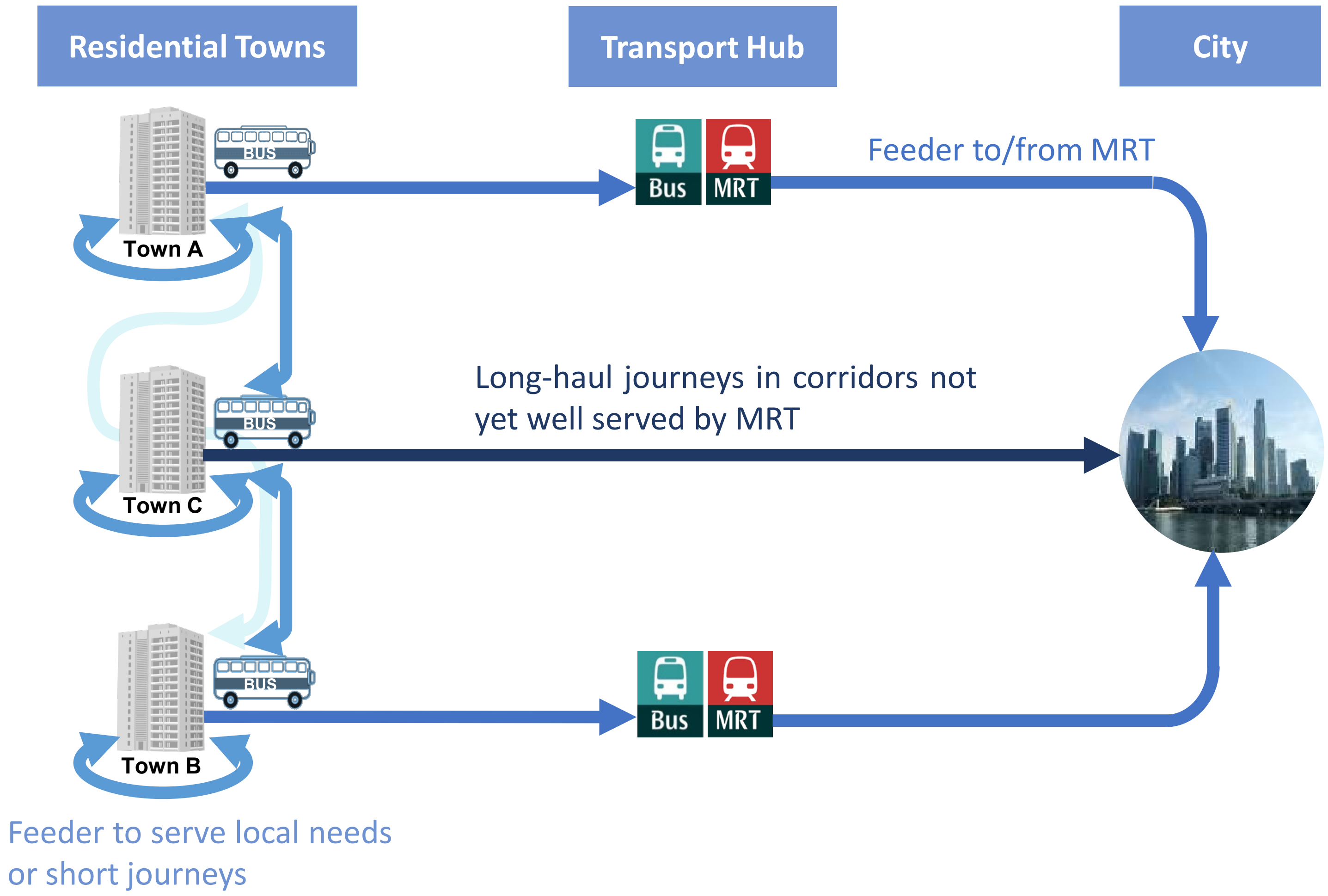
NYC (1.7X)

Hong Kong (1.5X)

# Population Densities around the World



# The Role of Public Buses in Singapore




## Guiding Principles in the Planning of Bus Services

1. Provide bus services within 400m coverage of developments, subject to minimum demand

2. Provide connections to nearby <u>key transport node</u> for onward connection to further destinations by rail or other bus services (hub-and-spoke), and to <u>key amenities</u>

3. Maintain overall bus network <u>financial sustainability</u>

# Why is Dynamic Bus Routing Important?

## Limitations of Fixed and Scheduled Services

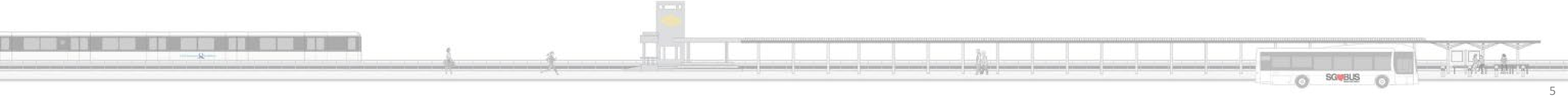
- Do not offer flexibility in responding to dynamic demand and traffic situations
- Services have to ply through entire fixed route even when there are no / little passengers along the way

## Rationalization of Low Demand Routes

- Under-performing services should ideally be rationalized to reduce cost
- May lead to routes being unserved, or faced with poor service levels

## Solution

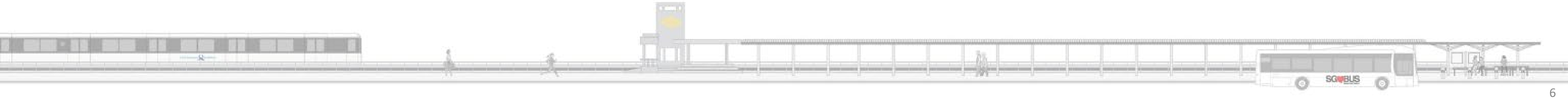
Feeding **on-demand bus services** into the existing transport network to improve connectivity, save costs, and maintain existing service standards



# Why is Dynamic Bus Routing Important?

**Benefits of Dynamic Bus Routing in Singapore**

- More flexible: Better adapt to commuters' demands, with potential to reduce journey times
- Direct and seamless travel for commuters
- Enables the rationalization of low-demand routes, while maintaining existing service levels
- Enables cost savings due to better resource optimisation and utilisation



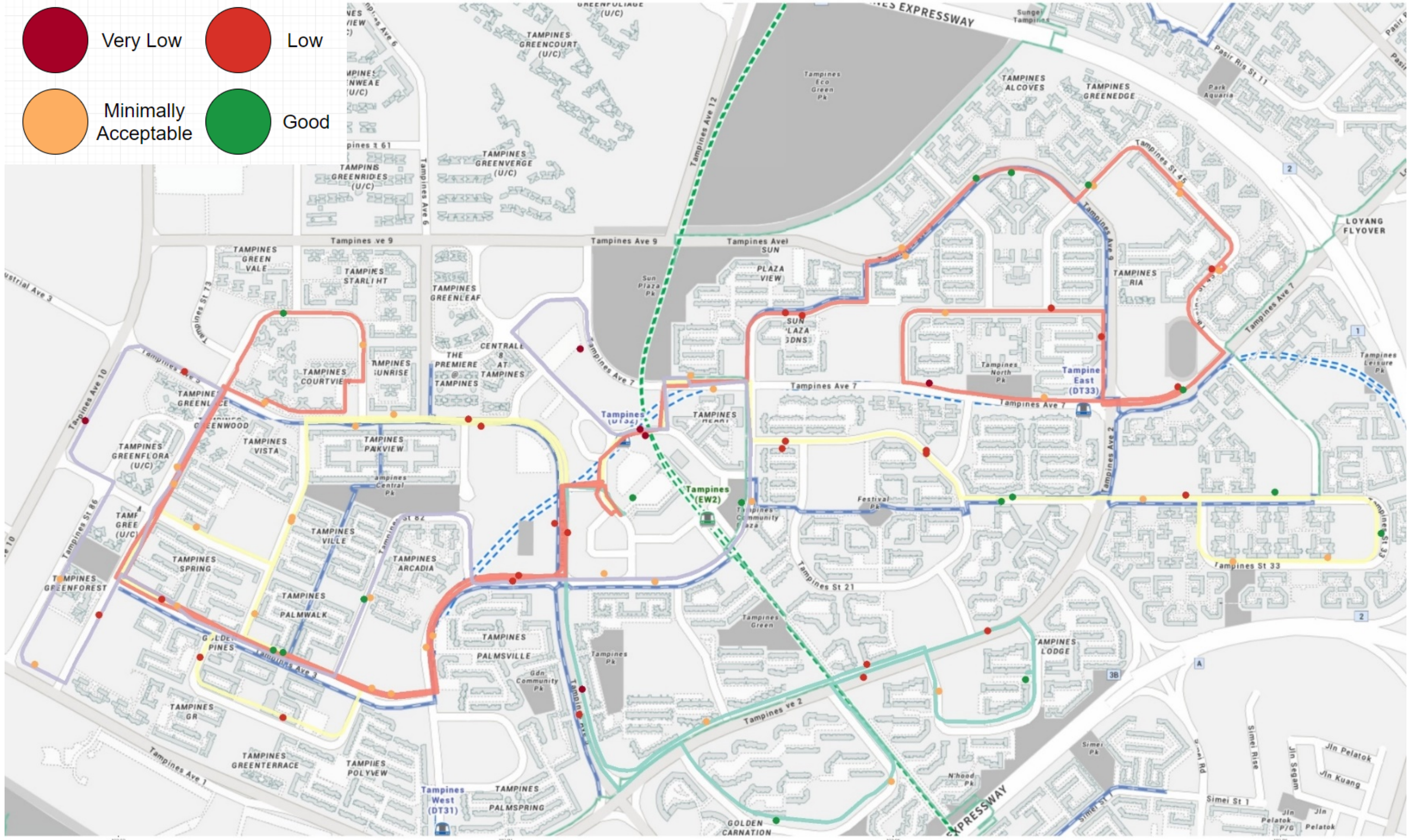
# Mix of Fixed and Scheduled Bus Services and Dynamically Routed Bus Services

## Areas / routes with consistently high and even demand across space and time

When fixed and scheduled services operate at high cost recovery ratio and consistently high loading, there is no need for rationalization

**Example: Mature Estate with High and Even Demand**

**Continue operating fixed and scheduled services**



# Mix of Fixed and Scheduled Bus Services and Dynamically Routed Bus Services

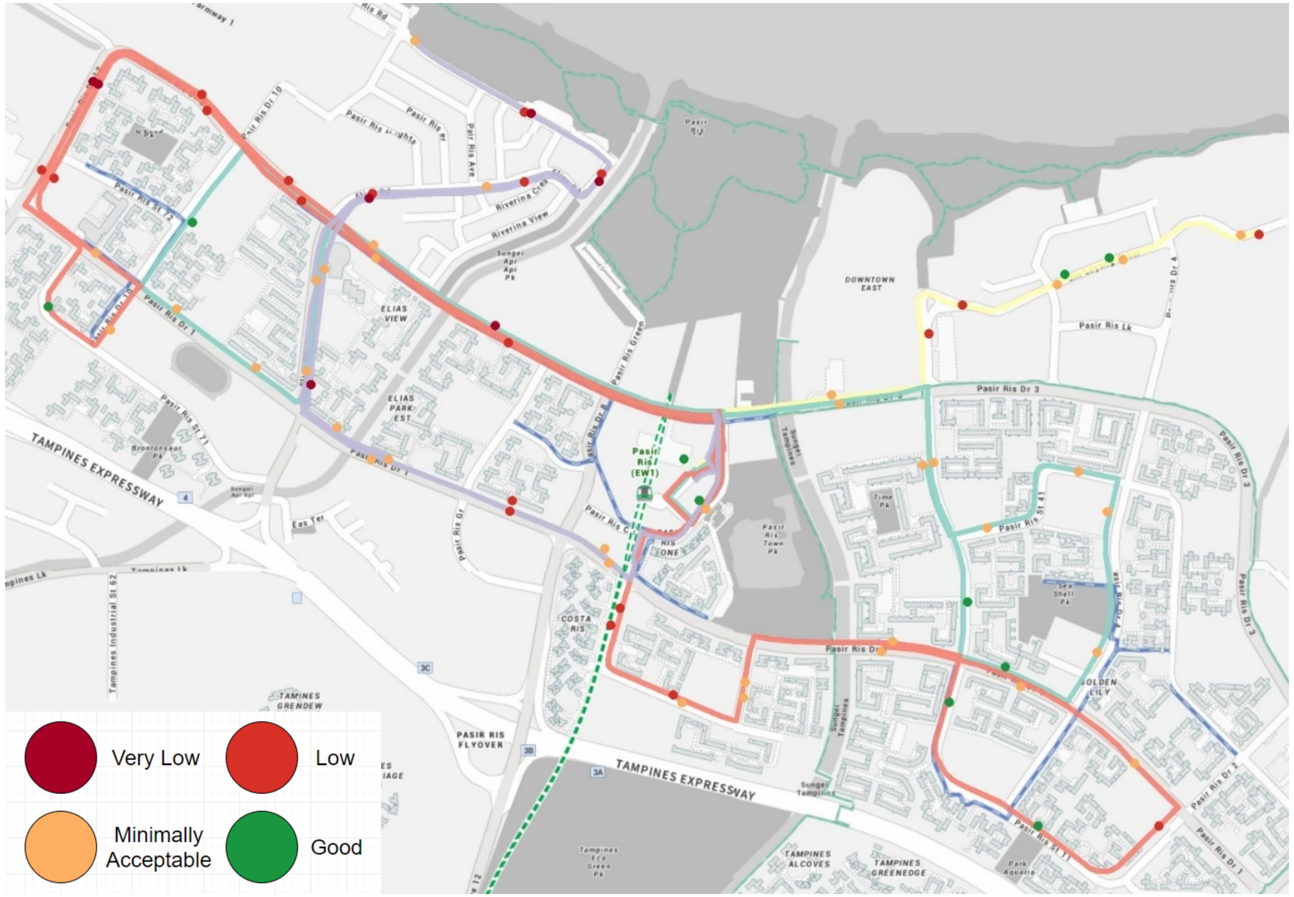
## Areas / routes with uneven spatial activity

Route contains both stops with (i) high boarding / alighting, and (ii) low boarding / alighting

Potential for spatial adjustment / rationalization of routes along corridors with low spatial activity

**Example: Mature Estate with Moderate Demand**

**Operate on-demand services to plug the connectivity gaps in low activity corridors**



# Mix of Fixed and Scheduled Bus Services and Dynamically Routed Bus Services

## Areas / routes with uneven temporal loading

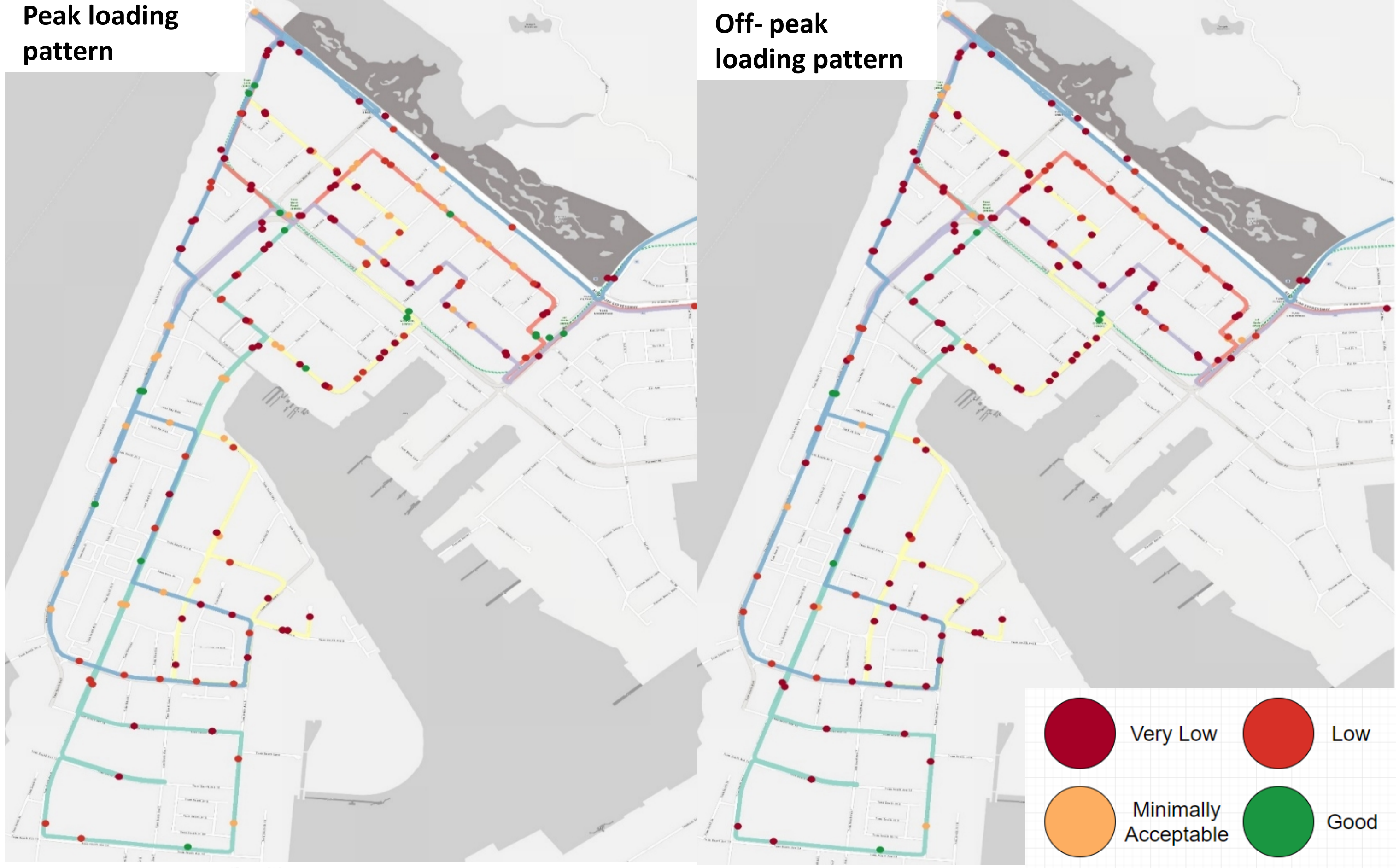
Exhibits peak-ish loading patterns

**Example: Industrial Estates**

**Operate on-demand services during off-peak periods**

Peak loading pattern

Off- peak loading pattern



# Mix of Fixed and Scheduled Bus Services and Dynamically Routed Bus Services

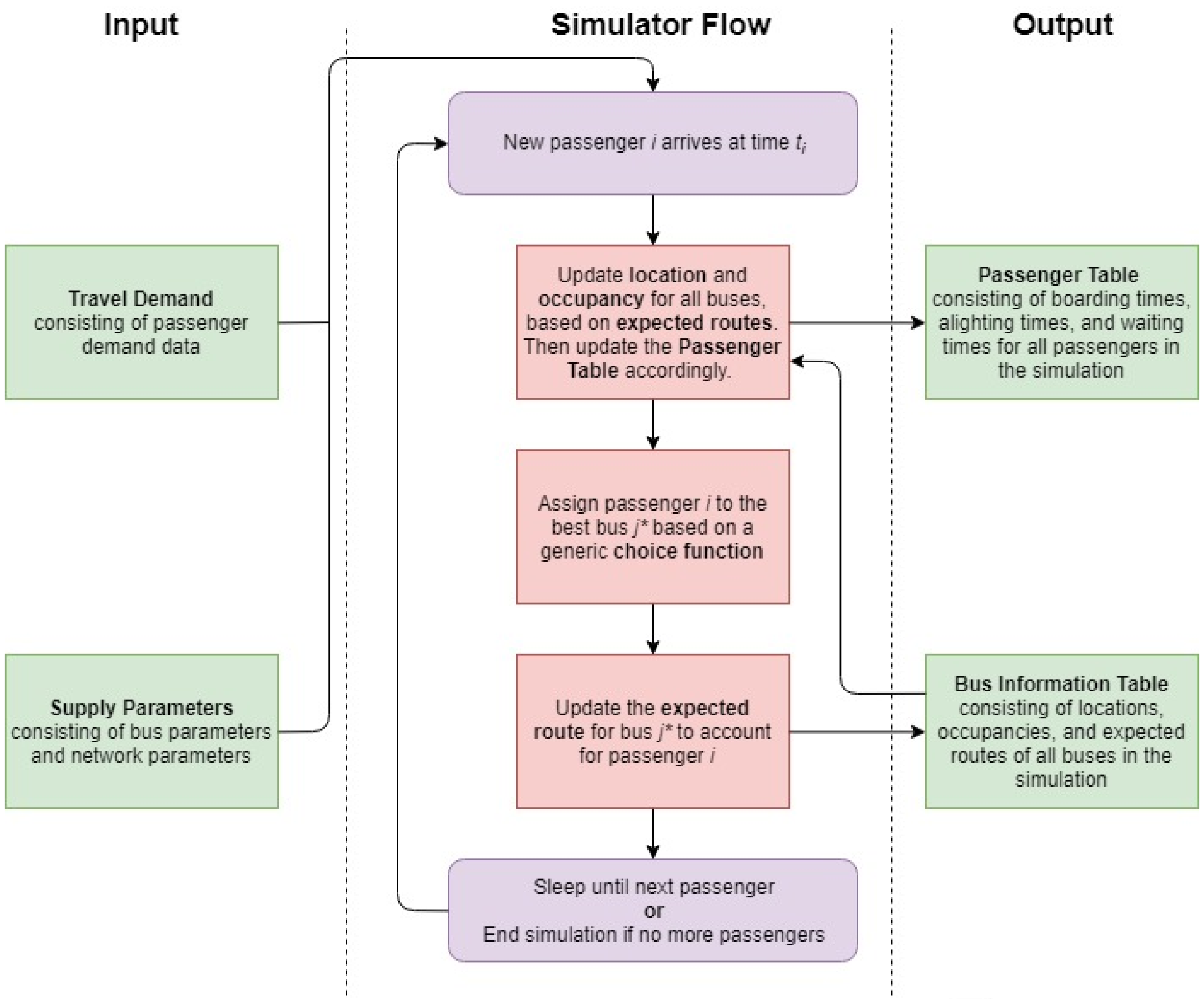
## To summarize: Three categories of regions/towns in Singapore:

1. Those with consistently high and even demand across space and time;

2. Those with uneven spatial activity (i.e. containing bus stops with both high and low utilization):
   - Enables spatial pruning, or headway adjustments, of bus services along corridors of low spatial activity
   - Enables the utilization of DRBs to plug the connectivity gaps in low activity corridors

3. Those with uneven temporal loading (i.e. peakish loading patterns)
   - Enables the utilization of DRBs to save costs during low-demand off-peak periods

# Simulator Overview




- Event-based, agent-based simulator
- Assumptions:
  - On-time passenger arrival
  - Minor flexibility in origins/destinations
  - Travel time based on historical values
  - Simulator only aware of **current demand**, not future conditions

TABLE I. INPUTS TO THE DYNAMIC ROUTING SIMULATOR

| *Travel Demand* | *Supply Parameters* |
|---|---|
| • Time of entry into system<br>• Origin<br>• Destination | • Fleet size<br>• Bus capacities<br>• Bus stop locations<br>• Dwell time parameters<br>• Cost matrix |

TABLE II. OUTPUTS FROM THE DYNAMIC ROUTING SIMULATOR

| *Passenger Table* | *Bus Information Table* |
|---|---|
| • Boarding time<br>• Alighting time<br>• Waiting time<br>• Waiting time reliability<br>• Travel time reliability | • Route taken<br>• Distance covered<br>• Occupancy over time |

# The Choice Function

Any reasonable choice function will include:

- A *routing function* that sequences boarding/alighting stops,
  - Effectively a Travelling Salesman Problem (TSP) on a directed graph!
- A cost matrix that denotes costs of travelling between the TSP edges, and
- A *cost function* that determines the assignment of passengers to vehicles.

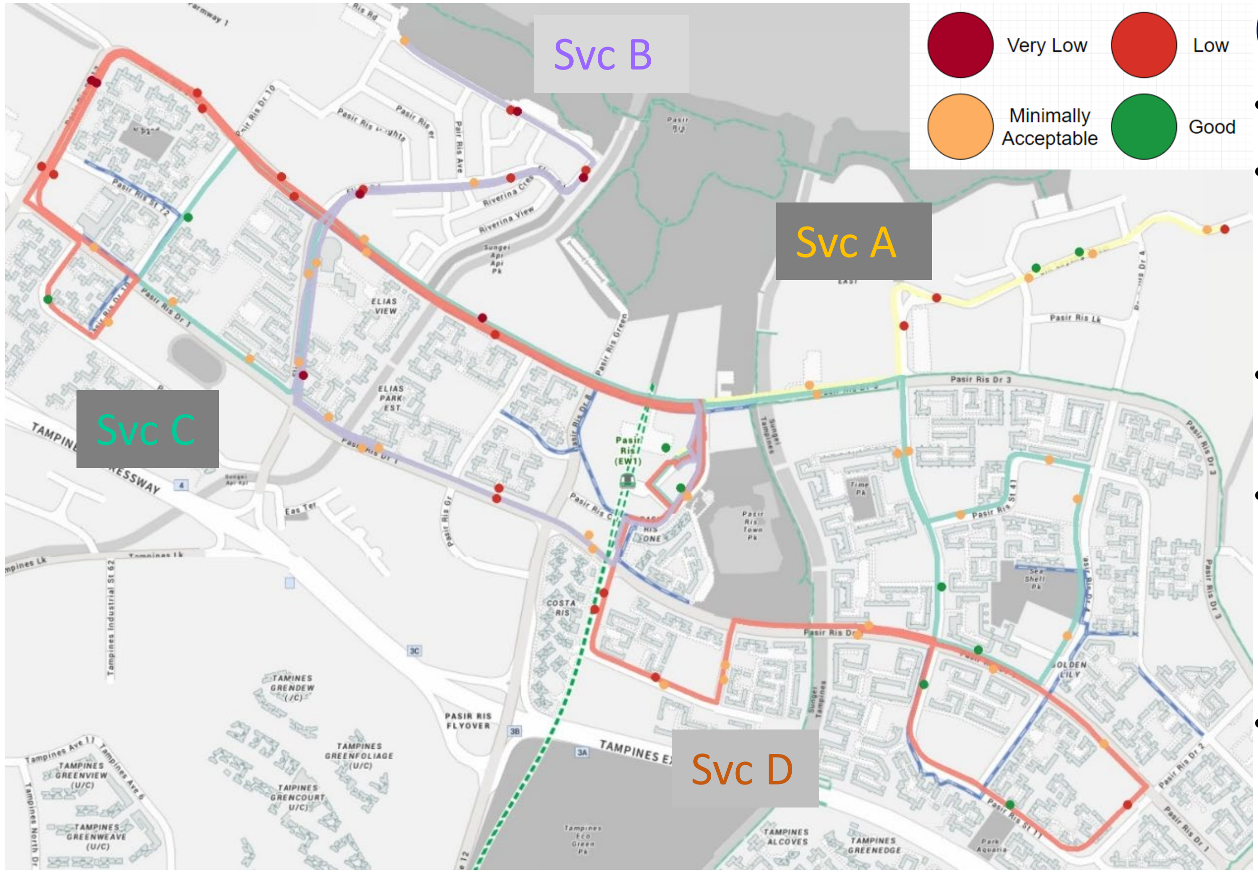
In the case study, the choice function iterates a modified version of the **insertion heuristic** developed by Jaw[1], returning the **best route** and **associated cost** for bus *j* to serve a new passenger arrival *i* as follows:

1. Obtain current route cost of bus *j*, $C_j = \sum_{k^*=1}^{m-1} t_{k^*}^{alight} - t_{k^*}^{entry} \ \forall k^* \epsilon M_j, k^* \neq i$
2. Find cheapest eligible edge to insert $L_i^{board}$
3. Find cheapest eligible edge to insert $L_i^{alight}$
4. Calculate new cost of route, $C_j^{new} = \sum_{k=1}^{m} t_k^{alight} - t_k^{entry} \ \forall k \in M_j$
5. Assign passenger *i* to the bus *j** that incurs least additional cost;
   $j^* = \arg\min(C_j^{new} - C_j) \ \forall j \in J$

[1]Jaw, J.J., Odoni, A.R., Psaraftis, H.N., Wilson, N.H.M., 1986. A heuristic algorithm for the multi-vehicle advance request dial-a-ride problem with time windows.

# Application of Dynamic Bus Routing in

# Areas with Uneven Spatial Activity

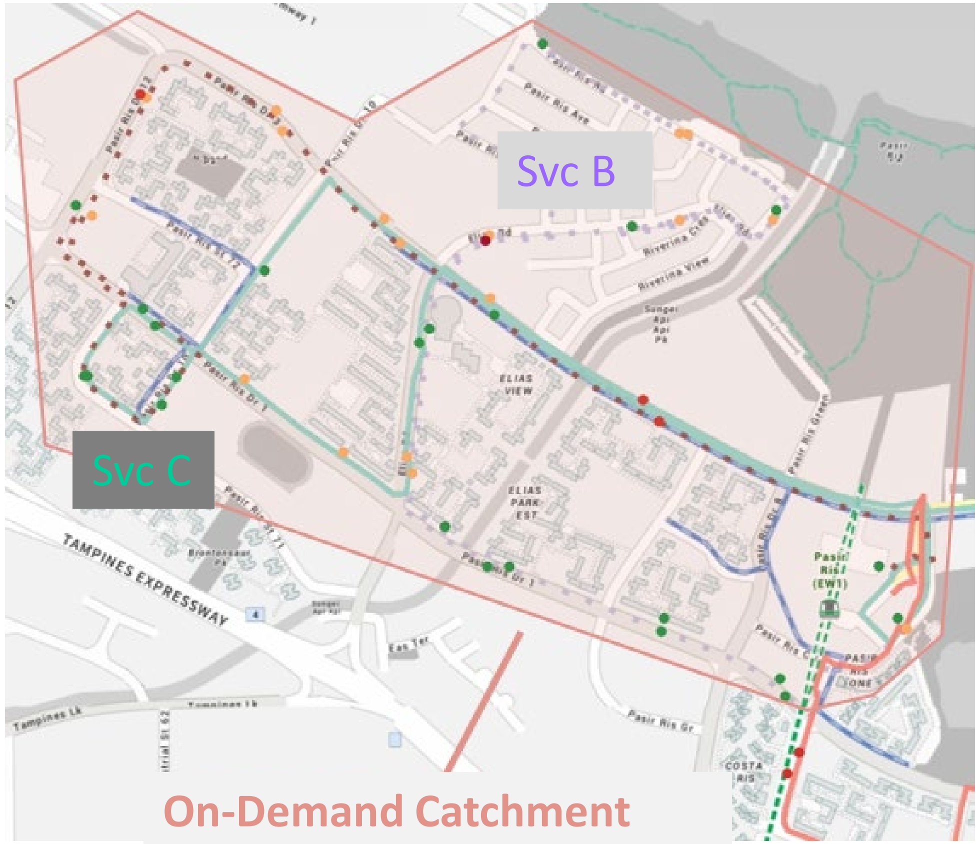



## Case Study: Overview of Town X

- Population-dense, predominantly residential
- High-rise public housing (high demand for public transport) coexists with private landed property (low demand for public transport)
  - This **spatial imbalance** creates pockets of inefficiency in the current feeder bus network
  - **The Challenge:** Can dynamic bus routing be used to better serve this demand?
- Key transport nodes:
  - MRT (subway) Station
- 4 feeder bus routes
  - Ply convoluted routes (Svcs C, D)
  - Bus stops have low spatial activity (Svcs B, part of C)
  - No point-to-point connectivity for majority of town
- Via dynamic bus routing:
  - Areas of *low and sporadic demand* will be efficiently served
  - High level-of-service corridors can be delegated to existing fixed and scheduled services

# Case Study: Results [1]

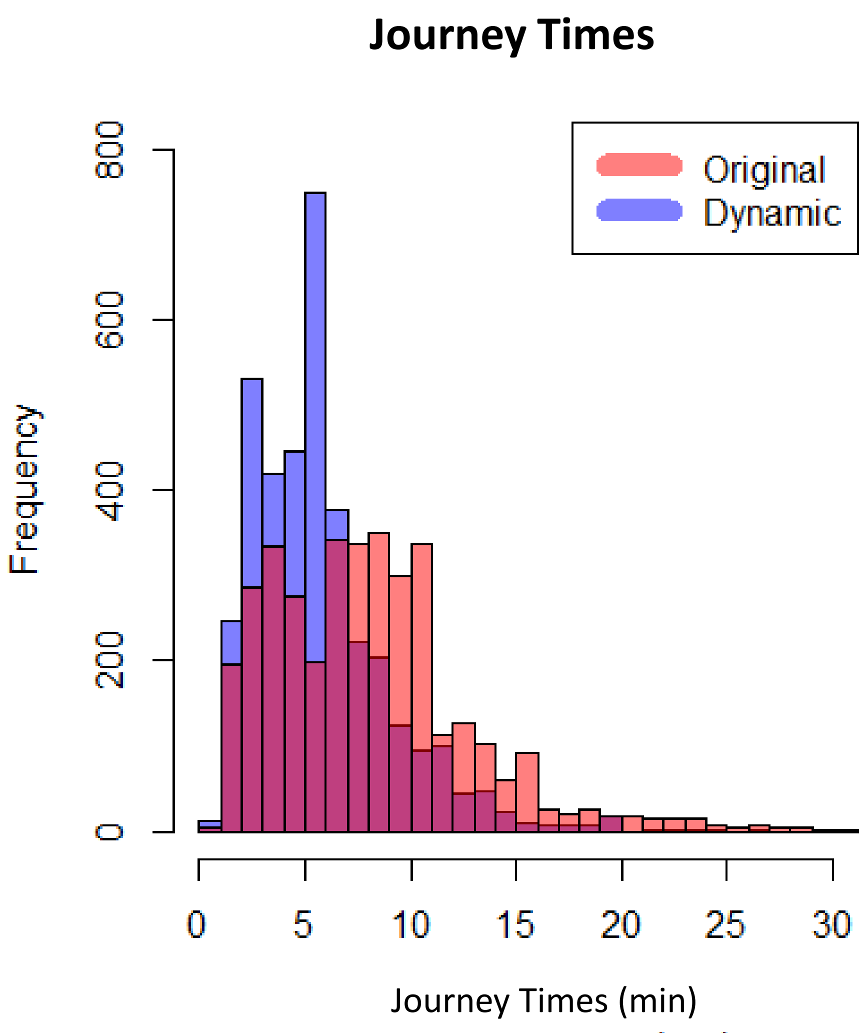
| Full Day {Svcs 403, 354, 358, 359} | | Present Day | On-Demand |
|---|---|---|---|
| Ridership | *FSS:* | 763 | 247 |
| | *DRB:* | - | 516 |
| Fleet Size | *FSS:* | 29 | 25 |
| | *DRB:* | - / - | 3 |
| Average Occupancy / Max Capacity | | 8.3 / 90 | 8.1 / 25 |
| Daily Cost Savings | | - | $2100 |
| Travel Time | *Average* | 9.1 | 7.6 |
| | *Maximum* | 21.6 | 20 |
| Wait Time | *Average* | 4.6 | 4.8 |
| | *Maximum* | 13.6 | 15.0 |
| % of Improved Journey Times | *Average* | NA | 78.5% |




**If Services B and C (partial) have their headways tripled…**

- 750 trips will be affected daily
- These rely on Svcs B/C (partial) for direct connectivity to their destination

# Case Study: Results [2]




# The First Step: Trialing Dynamic Bus Routing in Areas with Uneven Temporal Activity

## On-Demand Public Buses (ODPB) Trial

6 - 12 months trial which commenced in December 2018

### Objective

Leverage on demand-responsive technology solutions to optimise resources of low-demand public bus services during off-peak periods through the use of Dynamic Bus Routing

### Concept

- Identified regions of uneven temporal demand (low ridership during off-peak periods) to operate as ODPB
- Fixed and scheduled public bus services continue operations, but at reduced frequencies
- Waiting time to be no longer than the fixed and scheduled public bus services

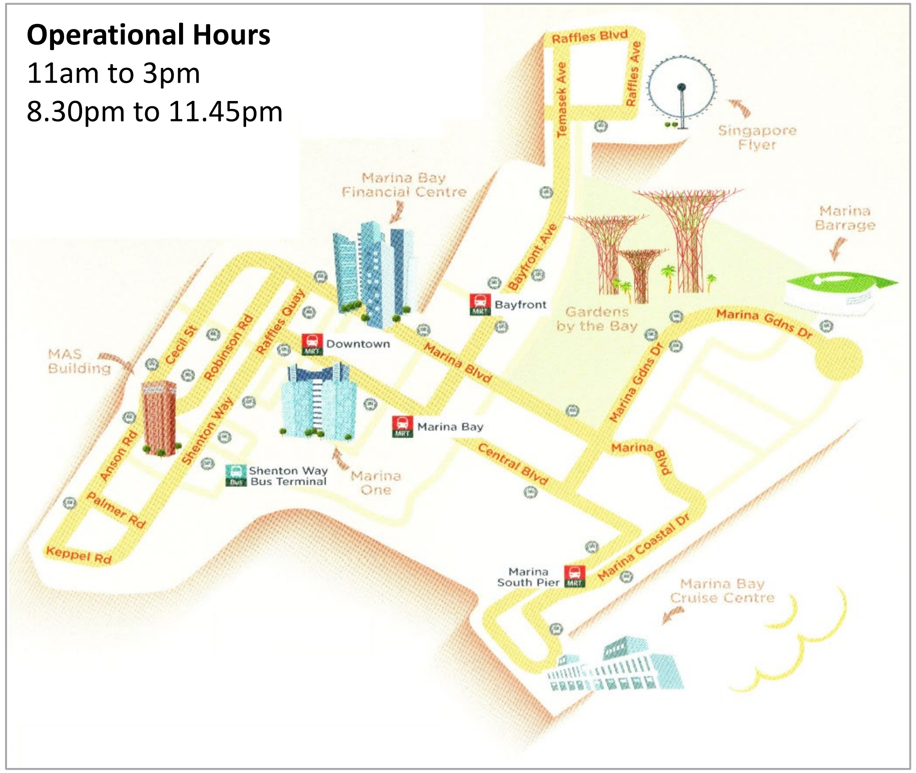
# ODPB Trial in Marina Bay / Shenton Way (CBD)

## Low-Demand Bus Services


Fixed and scheduled services 400 and 402 operates at increased headways of 40 minutes during ODPB operational hours, from the original 15 minutes

## ODPB Trial Geo-fence Area

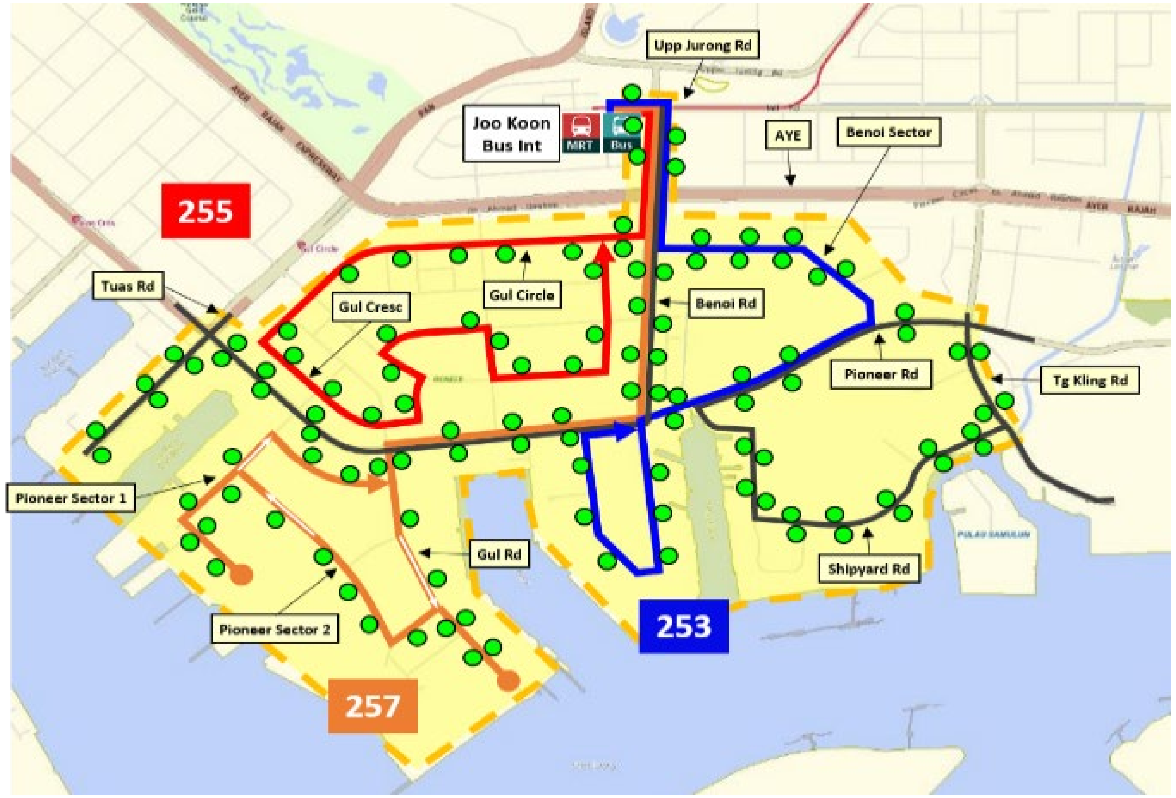
**Operational Hours**
11am to 3pm
8.30pm to 11.45pm




Within the geo-fence area, a commuter books an ODPB ride through a mobile application by Ministry of Movement, indicating which bus stop he/she wants to board and alight

# ODPB Trial in Joo Koon (Industrial Estate)

## Low-Demand Bus Services




Fixed and scheduled services 253, 255 and 257 operates at increased headways of 30 minutes during ODPB operational hours, from the original 10 - 15 minutes

## ODPB Trial Geo-fence Area

**Operational Hours**
11am to 3pm
8.30pm to 11.30pm


Within the geo-fence area, a commuter books an ODPB ride through a mobile application by Via, indicating which bus stop he/she wants to board and alight

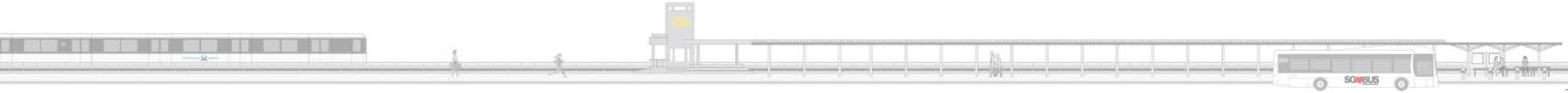
# Summary: What Have We Learned?

## What have we demonstrated?

- Dynamic Bus Routing in population-dense regions offers significant efficiency gains.
  - DBR can complement existing fixed-route services plying high-demand corridors, and hence optimize travel patterns *within towns*.
- Under the right circumstances, on-demand bus services offers benefits in terms of
  - Waiting and travel time savings for commuters
  - Improved intra-town connectivity
  - OpEx and CapEx savings for service providers

## What's next?

- A second proof-of-concept following the ODPB trial:
  - Smaller (and hence more nimble) buses
  - In a residential region of Singapore
  - Operating across the entire day



# Thank You