Motivation: With an increase in vehicles on the road and capacity of the roads remaining approximately constant, the speed of the traffic stream slows. This results in higher travel times and increased pollution. With the increasing popularity of on-demand mobility services like Uber and Grab the traffic demand has started to each road capacities more often, thereby enabling congestion to set in. All passengers inherently opt for the shortest route in the network in order to save travelling time, which ultimately results in blocked roads. All these factors lead to under-utilization of a city's intricately-built road network.

Many countries adopt the "odd-even rule" that allows only a section of the vehicles to operate on a given day. In the UK, they reduced congestion by pedestrianising city centres, thereby reducing driveable routes in the most populated areas. Others have suggested ride-sharing services such as UberPool and LyftLine, or public transport to lessen the traffic burden. Congestion is seen to lower drastically by incorporating micro-mobility options such as scooters, cycles, or walking. This enables customers to manoeuvre through crowded paths with ease. This also provides flexibility in choosing their preferred mode of transport based on accessibility and cost.

Problem Definition: We present an efficient algorithm to perform real-time congestion-aware routing of customer trips using a multi-class fleet of vehicles. The trip is divided into multiple legs in order to decrease the overall travel-time of the customer. We provide optimal transit points for each leg, e.g, walk 400m for the first mile, drive for 15 mins for the middle mile, walk 250m for the last mile. Customer requests are routed such that all demands are satisfied in minimum system cost.

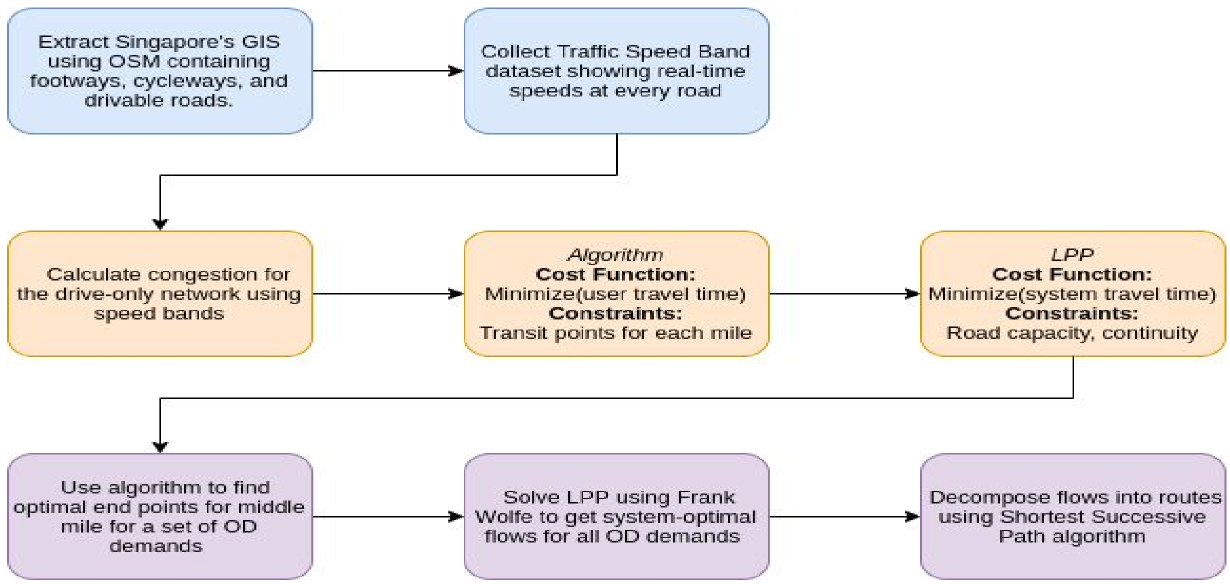
Background and Related Work:

1. In [1], car-pooling with 2-3 riders per vehicle was introduced in order to serve more customers with lesser vehicles on the road. [2] had rider-capacity of up to 10 simultaneous customers per vehicle. Results showed that 98% of the taxi rides currently served by over 13,000 taxis (of capacity 1) could be served with just 3,000 taxis (of capacity 4). This can result in greater traffic throughput for increasing demand or lesser congestion for constant demand.

2. [3] performed congestion-aware routing for a network consisting of Autonomous Mobility on Demand (AMoD) systems as they allow for system-wide coordination. However, customer trips were routed greedily using an A* approach. This results in a Wardrop User equilibrium [4] which is sub-optimal. Moreover, the solutions could not be used in real-time. [5] shows that by combining AMoD rides with moderate levels of walking, the overall system performance improved by 50%. However, there are no optimal transit points present to guide when to stop walking and start using an AMoD system. It also did not provide any route-recovery strategies for each demand.

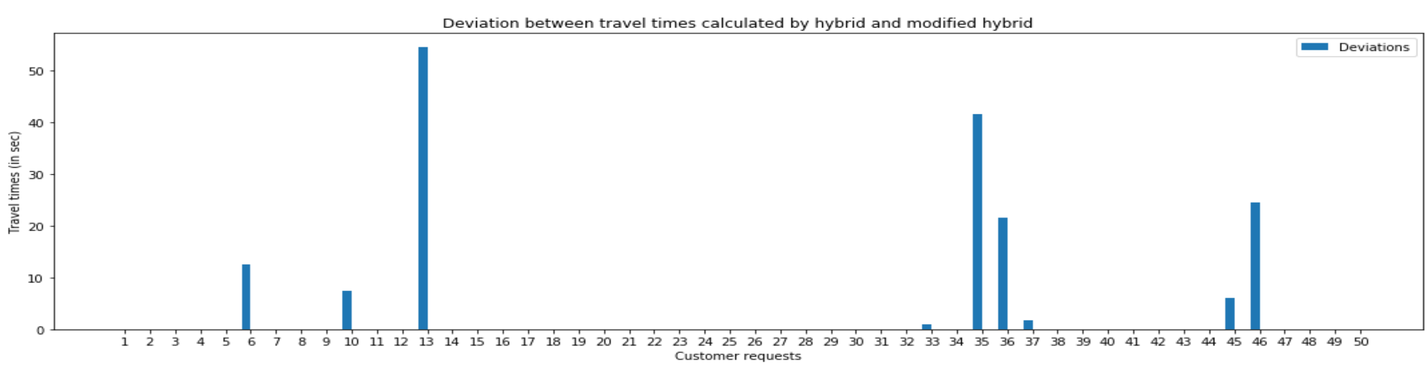
3. In [6], multi-class fleets were introduced that serviced a request using a combination of heterogeneous vehicles (cars, buggies, scooter, walking). However, there was a constraint on the fleet size due to its cost. Different vehicles were assigned to each customer sequentially and with the objective of minimizing travel time for each mile. This resulted in point-to-point routing of customers.

Approach: Each level/colour is a different phase in the project lifecycle.



Uniqueness: **(i)** Multi-class vehicles used for the first time for complete network utilization. **(ii)** Proposed a Modified Hybrid Search algorithm to find transit points resulting in minimum travel-time. Euclidean lengths are used as base comparisons for a quick search, resulting in a 64.5% query-save. **(iii)** Used Frank Wolfe optimization and Contraction Hierarchies instead of traditional traffic assignments, resulting in a 20% improvement in computational time. **(iv)** Performed route-recovery by defining a "maximum-neighbour" heuristic along with capacity-constrained Dijkstra. **(v)** Used only open source tools.

Results and Contributions:



Demand Size	Congestion Rate%	Waiting Queue Size	Cost of System (secs)
Off-peak: 70	0	0	253,263.78
Moderately-peak: 275	0	0	1,109,868.73
High-peak: 2884	0	60	73,576,342.89

Fig 1. Shows the deviation between travel times for optimal transits A-B and transits found by Modified Hybrid Search (50 trips). **There is an avg. delay of 3.42 secs and individual delay of <1min.**

Fig 2. Analyses congestion after routing for 3 demand sizes. **Congestion rate of 0% is achieved. Infeasible demands during high-peak (~2%) are added to a waiting queue. Avg. trip assignment time per customer is 5.23 min.**

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