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Microtransit optimization with transfers and virtual bus stops

Integer Optimization Project (15.083)

Executive summary

Microtransit offers riders a **cost-effective, on-demand** transportation alternative to fixed routes and paratransit services. With a dedicated app or online tool, passengers can easily request pickups within a specified service area, providing greater flexibility and convenience.

We propose a model that optimizes microtransit operations, with **high-capacity** busses traveling between **virtual bus stops** (vbs), leveraging flexibility in customers-vbs assignation and **transfers** at hubs locations.

Problem statement

We aim at developing an **offline** model that collects customer trips requests in **batchs**, and assign them to available busses of capacity Q. Busses travel along a network of virtual bus stops to facilitate the **vehicle-customer coordination**: they pick-up passengers at a bus stop within walking distance of their origin and will drop-off them off at another bus stop **within walking distance** of their destination. We also aim at **enabling transfers** at some hubs locations, where passengers may have to step out of a bus to wait for another bus that would bring him closer to his destination. Due to the **penibility** of transfers, only one transfer per passenger is allowed.

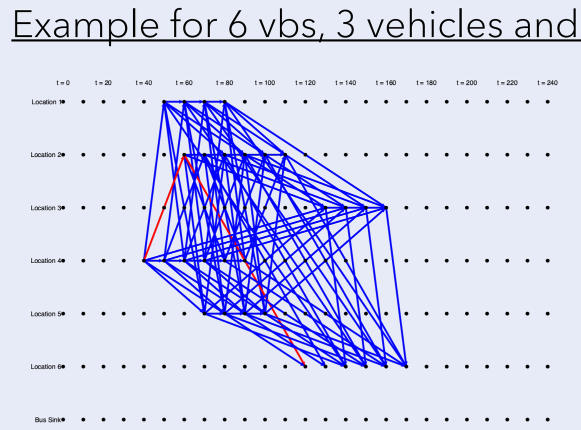
Customers can then be assigned to two types of **paths**:

- Direct : from a good pick-up vbs to a good drop-off vbs
- Indirect: from a good pick-up vbs to a good drop-off vbs, with a change of vehicle at a hub location

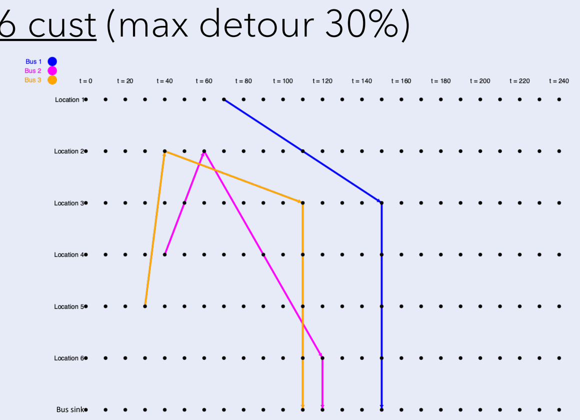
Time-space network

Goal: Encapsulate time windows, flexible assignation and capacity constraints in the definition of the network.

Example for 6 vbs, 3 vehicles and 6 cust (max detour 30%)



Possible vs selected arcs for a customer



Selected arcs for the 3 vehicles

The model relies on the definition of many parameters, including:

- $\mathrm{O(i,p)}$: possible t-s nodes to pick-up cust *i* if his path *p* is selected
- $\mathrm{D(i,p)}$: possible t-s nodes to drop-off cust *i* if his path *p* is selected
- $\mathrm{H(i,p)}$: possible t-s nodes to transfer cust *i* if his path *p* is selected

Formulation

Decision variables: van & cust routing, cust path selection

Multi-objective function:

$$\lambda_1\, Cust\ Walking + \lambda_2 Cust\ Waiting + \lambda_3\ Cust\ Traveling +$$
$$\lambda_4 Veh\ driving + \lambda_5 \#\ Veh + \lambda_6 \#\ Cust\ Transfers + \lambda_7 Unmet\ demand$$

Constraints:

- **Veh-arc:** Max one vehicle assigned to each t-s arc
- **Path selection:** Assign max one path per customer
- **Path consistency:** Pick-up and drop-off consistent with path
- **Transfer validity:** No transfer possible if direct path selected
- **Transfer flow:** Bus change at a hub consistent with path
- **Pass-Veh link:** Passengers can only travel between vbs with a bus
- **Capacity**: Max Q customers carried on each t-s arc
- **Depot:** Max one bus leaves each depot location
- **Cust flow:** Flow balance except at selected pick-up & drop-off
- **Veh flow:** Flow balance except at depot and sink

Actions taken to improve scalability:

- **Arcs reduction:** Reducing the number of arcs that each customer can reach, based on max detour from ideal route time (walking to closest pick-up vbs, walking from closest pick-up drop-off and driving in between)
- **Removed index k:** No track of the index k in the decision variables, thanks to duplication of depot locations and hubs locations to control passengers transfers.

Data inputs

Map inputs:

- Virtual bus stops (ids, locations)
- Customer requests (ids, time, load, locations)
- Vehicles (depot locations)

Model inputs:

- Max detour ratio
- Max walking distance
- Offer type:
  - Benchmark 1 ~ Taxis
  - Benchmark 2 ~ On-demand busses
  - Benchmark 3 ~ Flexible on-demand busses
  - Benchmark 4 ~ Flexibility + High capacity + Transfers

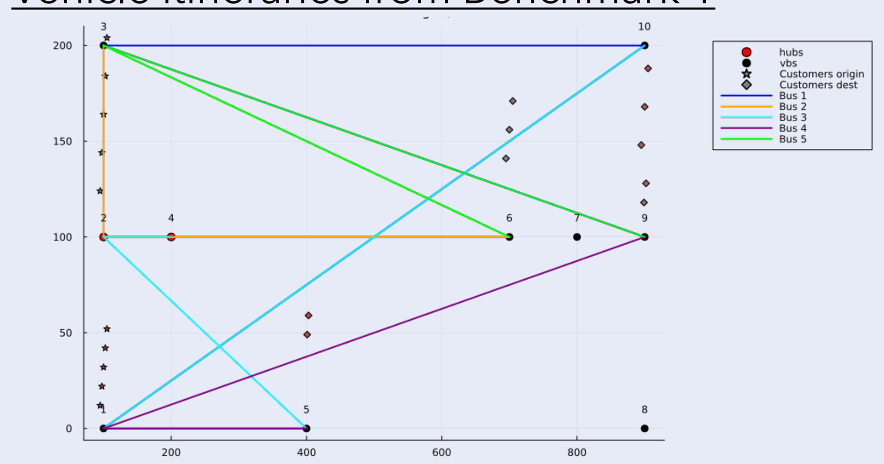
Key findings

Comparison of the solution for different benchmarks (with 10 cust, 10 vbs, 5 veh)

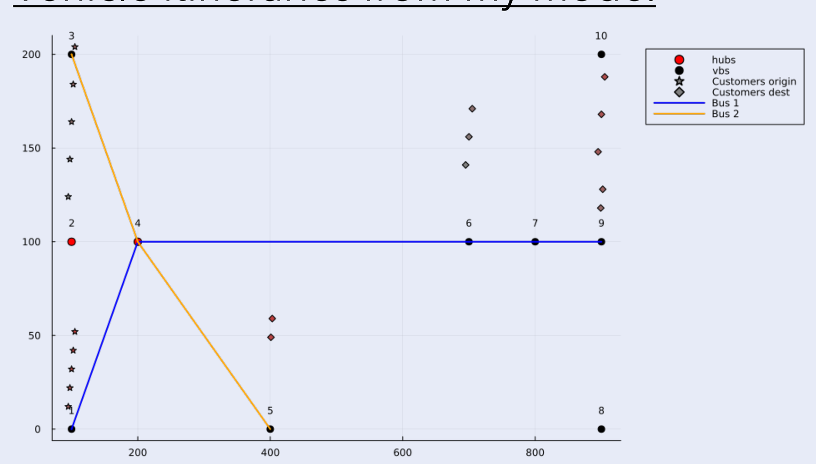
		Benchmark 1	Benchmark 2	Benchmark 3	My model
Customer KPIs	Mean walking time	42	42	64	76
	Mean waiting time	158	18	11	11
	Mean traveling time	162	176	153	150
	Route efficiency	73%	93%	94%	91%
	Mean # transfers	0	0	0	0.2
Vehicles KPIs	# Vehicles used	5	3	3	2
	Total distance traveled	930	129	113	48
	Mean service time	930	215	189	120
	Mean empty time	281	0	0	0
	Mean capacity	0.4	1.6	1.3	2.1
	Solving time (sec)	3	1.6	23	101

+ High-Capacity + Flexibility + Transfers

Vehicle itineraries from Benchmark 1



Vehicle itineraries from my model



- **High capacity** improves customers waiting time by 90%, route efficiency by 20% and vehicle distance by 80%
- **Flexibility** improves vehicle utilization by 12%, while offering similar customers walking time and route efficiency
- **Transfers** further improve vehicle utilization by 33%,distance by 60% *(especially for clustered customer requests)*, while offering route efficiency and slightly increasing customers walking times

Scalability analysis

Uniformly-distributed customers

Run time (sec)	With k	Without k
5 cust, 6 vbs, 3 veh	0.9	0.6
5 cust, 10 vbs, 5 veh	26.3	2.9
10 cust, 6 vbs, 3 veh	2.4	1.6
10 cust, 6 vbs, 5 veh	2.3	1.5
10 cust, 10 vbs, 5 veh	205.1	9.5

Clustered customers

Run time (sec)	With k	Without k
5 cust, 6 vbs, 3 veh	1.3	0.5
5 cust, 10 vbs, 5 veh	97.5	21.4
10 cust, 6 vbs, 3 veh	2.7	0.8
10 cust, 6 vbs, 5 veh	5.2	0.8
10 cust, 10 vbs, 5 veh	444.8	100.7

Removing k speeds up the optimization by up to **20x** !

Impact

- **Transfers:** Enabling transfers at strategic hubs locations has high potential in reducing microtransit costs (# vehicles and distance)
- **High-capacity busses:** Increasing capacity allows to carry together passengers with similar itineraries and thus reduce costs.
- **Flexible assignation**: Enabling flexibility in the allocation of pick-up and drop-off vbs allows to reduce microtransit costs while not affecting customers too much.

Next steps

- **Scalability:** Leverage column and/or row generation to further improve the model scalability
- **Real-world test:** Test model on real-world customer requests and ajust the coefficients of the objective function to build solutions that meet both customers and transportation companies needs.