User-focused Microtransit for Students' After-School Activities

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ABSTRACT

- This study investigates a user-focused microtransit service designed for students with after-school activities, generating a synthetic student population and their trip requests, determining the routes solving a VRPPDTW.
- The VRPPDTW includes scheduling of drivers with mandatory breaks and maximum shift durations, while also minimizing unassigned trips, waiting and travel times, and route imbalance. Various scenarios are analyzed to assess the impact of fleet size, fare levels, and service parameters on performance.
- Results show that larger fleets achieve higher occupancy and better kilometer utilization and can surpass a system efficiency of 1, indicating the distance travelled by the service is lower than individual trips.

VRPPDTW FORMULATION ASSUMPTIONS

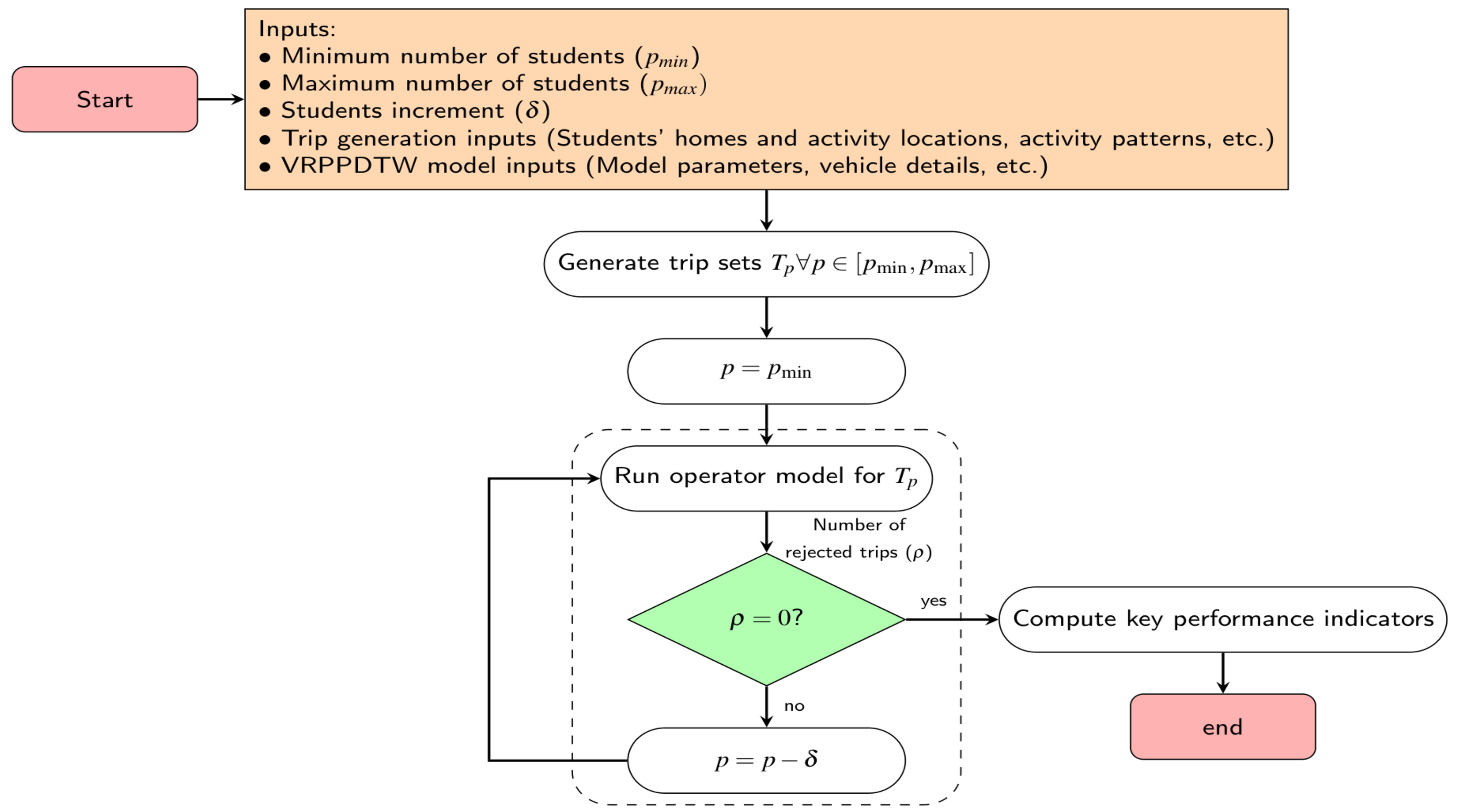
- A fixed fleet of vehicles is used, each vehicle constrained to operate within a time frame defined by the driver's shift.
- Drivers are entitled to a mandatory break during a specified time window, which can be scheduled flexibly along the route.
- Vehicle routes must comply with capacity limits and are required to start and end at a central depot.
- Vehicle routes must be equilibrated to ensure that drivers have a similar work load.
- Each trip request includes a booking type, which indicates the direction of the trip and can be one of the following: going (from home to an activity location), return (from an activity location to home), or between (between two activity locations). Going trips must have a defined drop-off time at the activity location, return trips must have a defined pickup time, and between trips must have both pickup and drop-off times specified.
- Each trip request is divided in two tasks: a pickup and a drop-off. Each task is associated with specific time windows.
- Requests are time-sensitive, so vehicles cannot arrive at the drop-off location before the start of time window and travel times should be minimal.

VRPPDTW OBJECTIVE FUNCTION WITH PENALTY INTEGRATION

$$C = \sum_{r\in R}\Bigg[\underbrace{\sum_{g\in V}(v_{g,r}\times \mathrm{fvc}_g)}_{\text{fixed vehicle cost}} + \underbrace{\sum_{\substack{q_i,q_j\in Q_r\\ q_j \text{ follows } q_i}}\big(c_{\text{travel}}(q_i,q_j)+c_{\text{task}}(q_j)\big)}_{\text{travel and task costs}} + \underbrace{\sum_{q\in Q_r\cap B}\mathrm{TP}_q}_{\text{trip penalties}} + \underbrace{\mathrm{BP}_r}_{\text{break timing penalties}}\Bigg] + \underbrace{M\sum_{r\in R}(B_r-\bar{B})^2}_{\text{workload balancing penalty}} + \underbrace{\frac{1}{2}M^3\sum_{s\in U}(11-\mathrm{pri}_s)}_{\text{unassigned task penalties}}$$

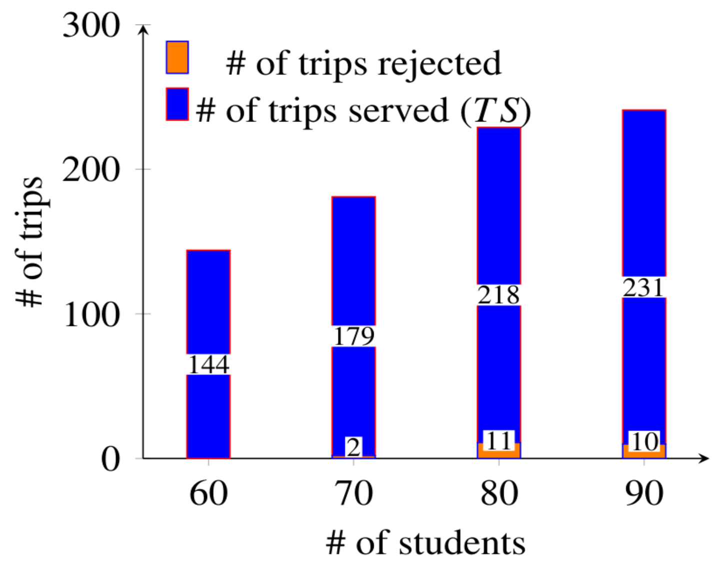
- JSPRIT optimization library is used to solve the VRPPDTW, applying a metaheuristic approach grounded in the Ruin-and-Recreate strategy

TRIP GENERATION & ROUTE CALCULATION METHODOLOGY

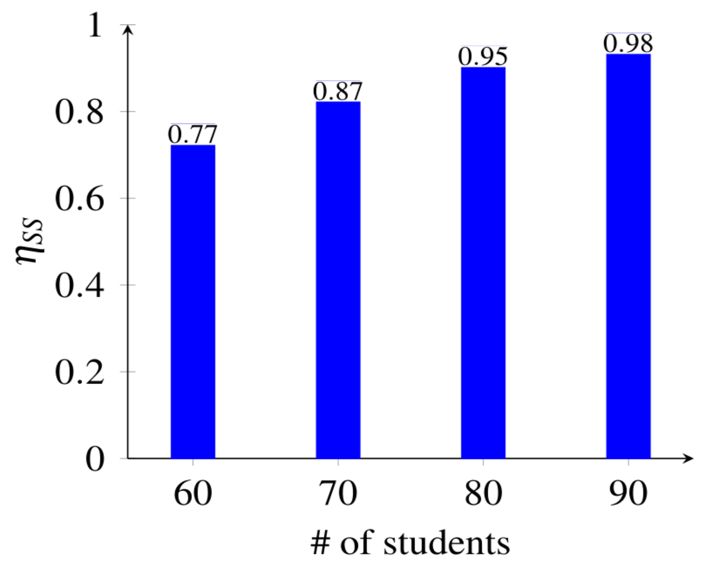


KEY PERFORMANCE INDICATORS

Perspective	Description	Indicator
Driver	Average shift duration per day	SD_{avg}
	Average number of trips per shift	TpS_{avg}
Passenger	Average waiting time [min]	WT_{avg}
	Average extra travel time [min]	ETT_{avg}
System-level	Number of trips served	TS
	Vehicle Kilometers Traveled [km]	VKT
	Passenger Kilometers Traveled [km]	PKT
	Average seating occupation	O_{avg}
	Maximum seating occupation	O_{max}
City-level	Shared Service System efficiency	η_{SS}
	Difference in the number of cars required	ΔPV



(a) Trips served and rejected

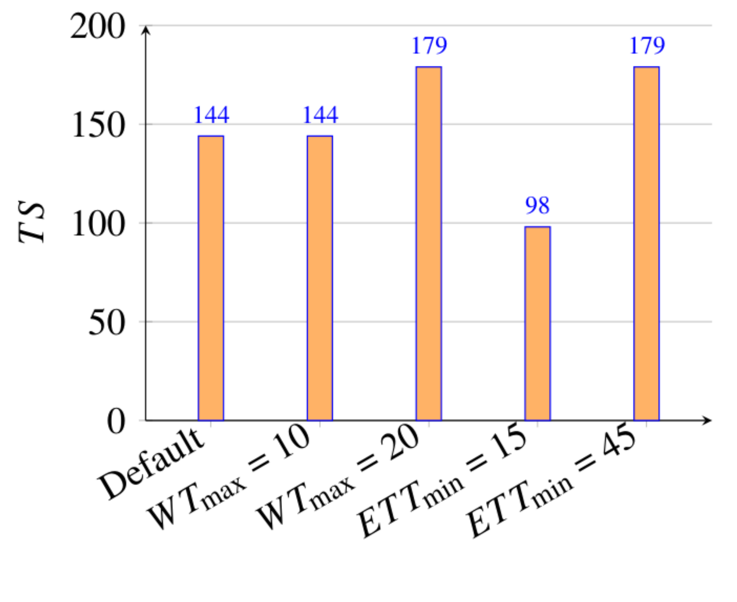


(b) System efficiency (η_{SS})

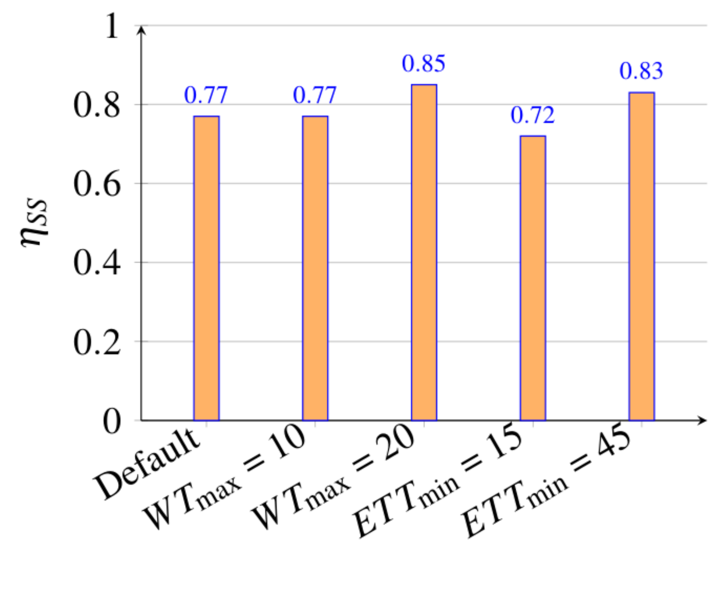
Perspective	Indicator	Value
Driver	SD_{avg}	5.8
	TpS_{avg}	14.4
Passenger	WT_{avg}	12
	ETT_{avg}	10
System-level	TS	144
	VKT	829
	PKT	488
	O_{avg}	2.1
	O_{max}	6
City-level	η_{SS}	0.77
	ΔPV	-83%

Fleet size	10	15	20	25
TS	179	266	372	458
TpS_{avg}	17.9	17.7	18.6	18.3
η_{SS}	0.83	0.93	1.04	1.12
O_{avg}	2.3	2.7	2.5	3.2
ETT_{agv}	16.2	16.2	11.4	20.0

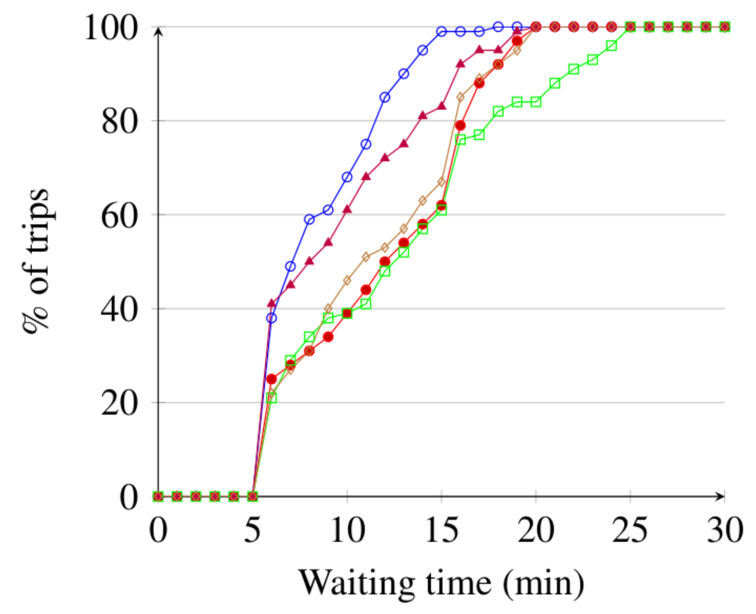
Fig. 1 Performance by number of students, perspective and fleet size



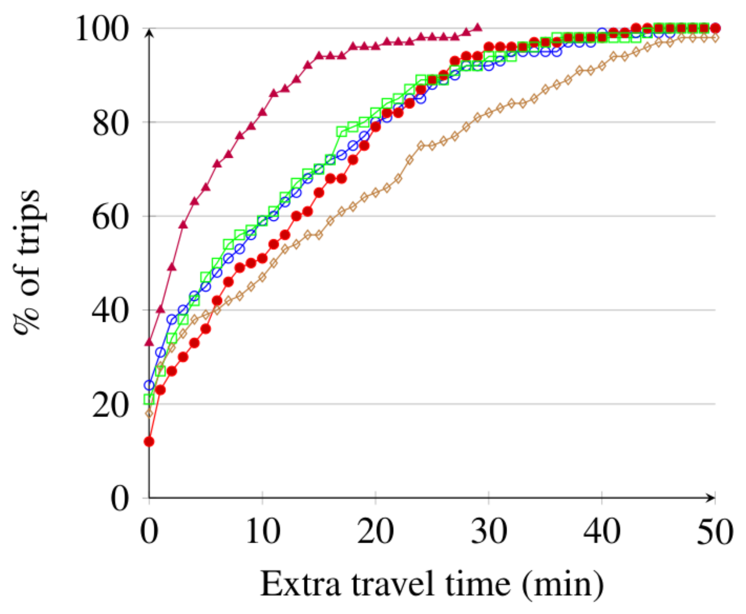
(a) Number of trips served (TS)



(b) System Efficiency (η_{SS})



(c) Empirical cumulative distribution of trips by waiting time

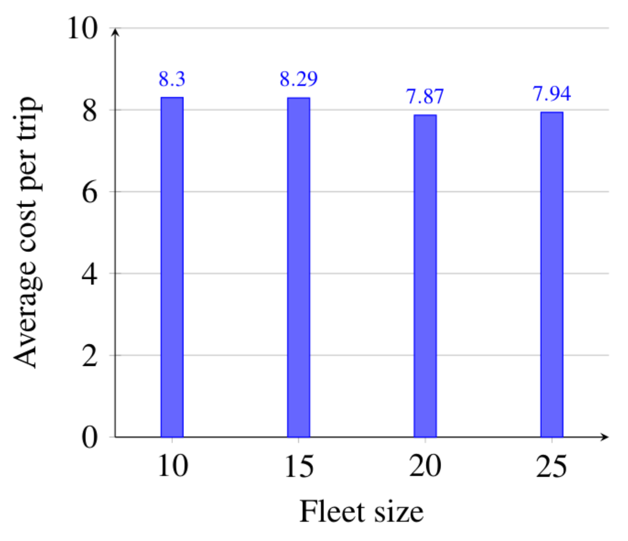


(d) Empirical cumulative distribution of trips by extra travel times

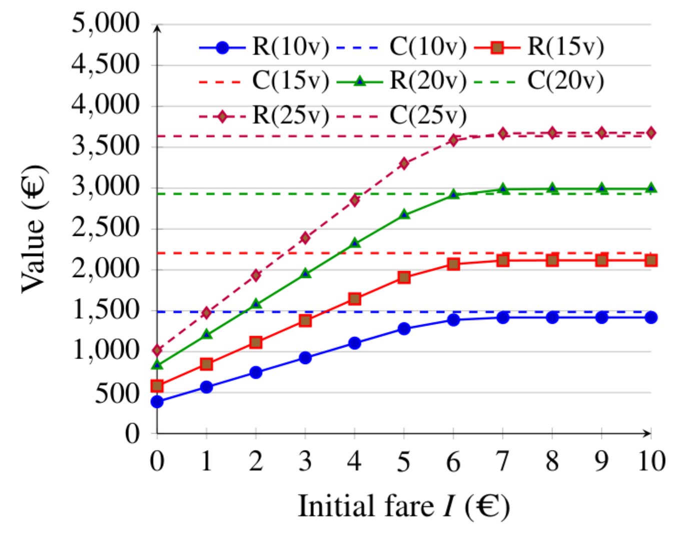
WT_max = 15 min and ETT_min = 30 min (default) — WT_max = 10 min — WT_max = 20 min — ETT_min = 15 min — ETT_min = 45 min

Fig. 2 Performance Indicators for Different WT_max and ETT_min

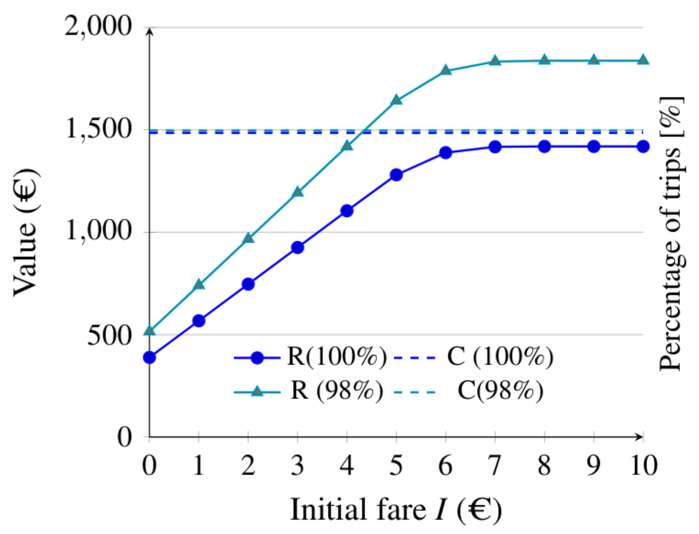
ECONOMIC ANALYSIS OF MICROTRANSIT SERVICE



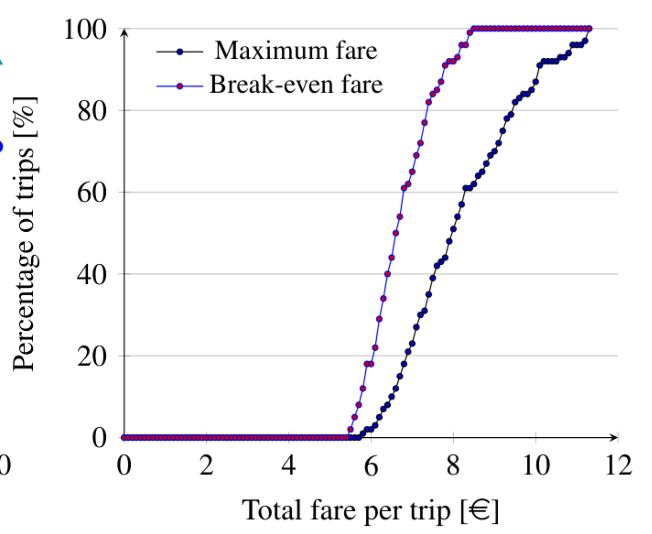
(a) Average cost per trip for different fleet sizes



(b) Daily revenue (R) and cost (C) comparison across fleet sizes for variable I and $\lambda = 0.5$



(a) Daily revenue (R) and cost(C) comparison for a fleet of 10 vehicles under scenarios serving 100% and 98% of trips for variable I and $\lambda = 0.5$



(b) Empirical cumulative distribution of trip fares at break-even and maximum fare levels for the scenario serving 98% of trips with 10 vehicles

CONCLUSIONS & FUTURE WORK

- A fleet of 10 vehicles serving 144 trips for 60 students can reduce the number of cars required by 83%, while maintaining a system efficiency of 0.77, adding 23% to travel distance compared to direct trips.
- For fleets of 20 vehicles or more, system efficiency exceeds 1,indicating that the total distance traveled becomes even lower than the sum of individual direct trips.
- Increasing the allowed waiting time by 5 minutes or travel time by 15 minutes results in a 24% gain in capacity, whereas stricter constraints can significantly reduce the number of trips served.
- A zero-rejection policy is only viable for fleets larger than 20 vehicles with high fare levels. Allowing a 2% rejection rate, substantially improves viability, enabling even the smallest fleet of 10 vehicles to operate sustainably, with break-even fares 25% lower than taxi rates.
- Additional strategies, such as limiting the service area or adding designated stops, should be explored in future research to enhance user adoption and service viability.

ACKNOWLEDGEMENT

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