Reliable Data-Driven Estimation of Accessibility in Demand-Responsive Transport

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Context

➢ Accessibility:

The ease with which people can reach surrounding opportunities, such as schools, shops, or jobs via transportation [1].

➢ Challenges of Accessibility:

Conventional Public Transportation (CPT), such as trains and buses, often provides limited coverage in low-density suburban areas due to high operational costs and low passenger demand [2].

Inequality of Transit ➡ **Car dependency** ➡ **Environmental, Social and Economic unsustainability**

Research Questions

1. **How can accessibility be reliably estimated for Demand-Responsive Transport (DRT) despite its stochastic travel times?**
2. **To what extent does Demand-Responsive Transport improve accessibility and reduce inequality compared to conventional public transport?**

Methodology

I. Definition of Accessibility

$$acc(u) = \sum_{u' \in C(u,t)} O_{u'} \quad \text{Such that}$$

$$C(u,t) = \{u \in C \mid T(u,u',t) \leq \tau\} \quad \text{Where:}$$

$C(u,t)$: The set of reachable centroids departing from centroid of hexagon u at time t.

$T(u,u',t)$: Travel time from centroid u to centroid u', departing at time t.

τ : Maximum tolerated travel time threshold.

II. Unified modelling of DRT with CPT

❑ We unify DRT and CPT within a time-expanded graph by introducing virtual connections that represent flexible trips.

❑ This approach enables realistic multimodal accessibility analysis, capturing both scheduled services and on-demand mobility within a single framework.

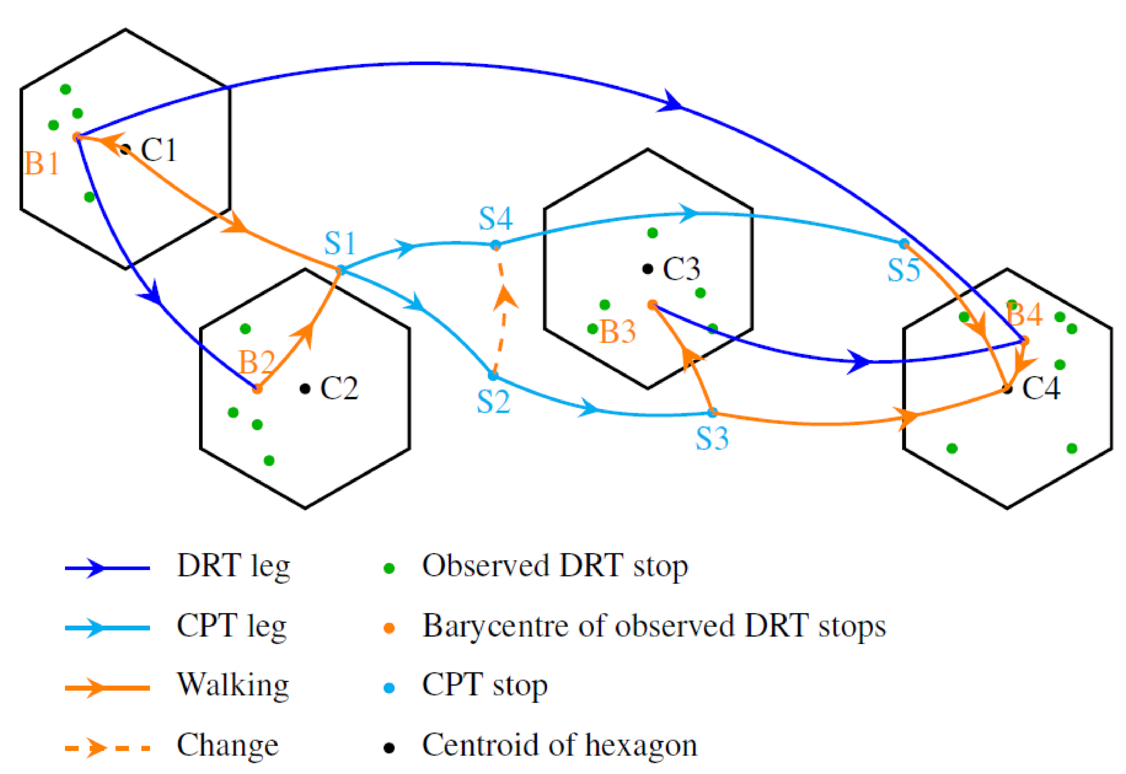

Figure 1. Illustration of integrated DRT with CPT.

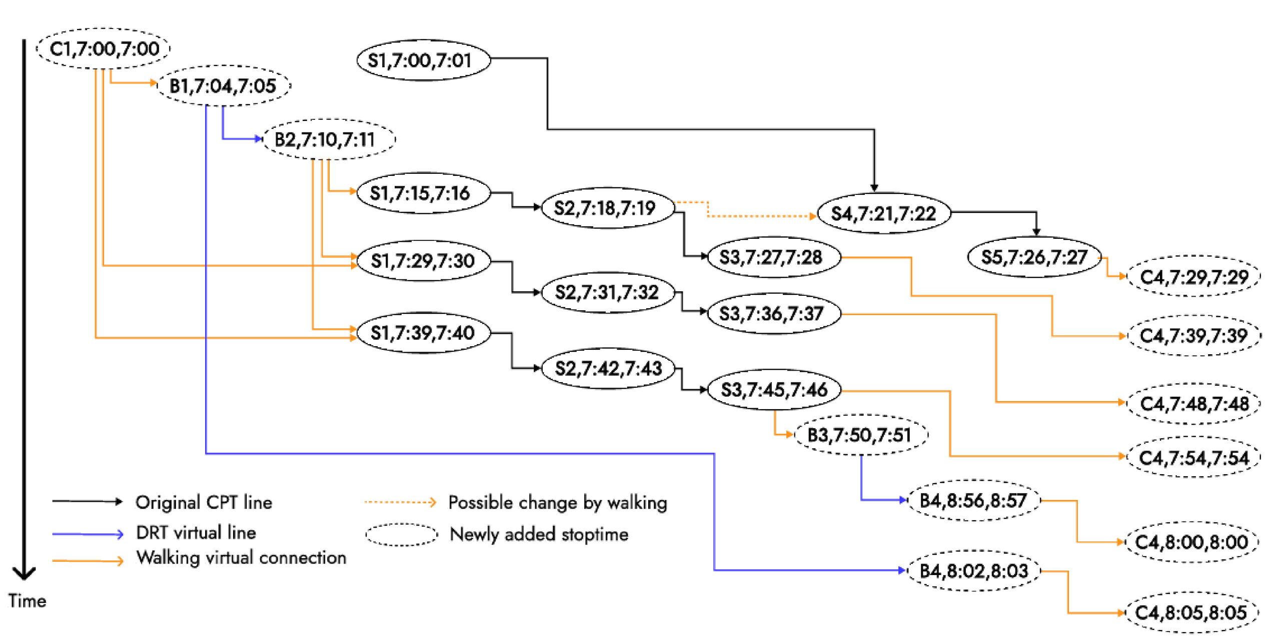

Figure 2. Enriched Time-Expanded Graph, representing CPT integrated with DRT and walking connections.

III. Probabilistic machine learning (PML) for reliable travel time estimation

❑ We use probabilistic machine learning models to estimate full travel time distributions, capturing the inherent uncertainty of DRT operations.

❑ These distributions enable reliable accessibility analysis by providing conservative travel time estimates based on selected percentile

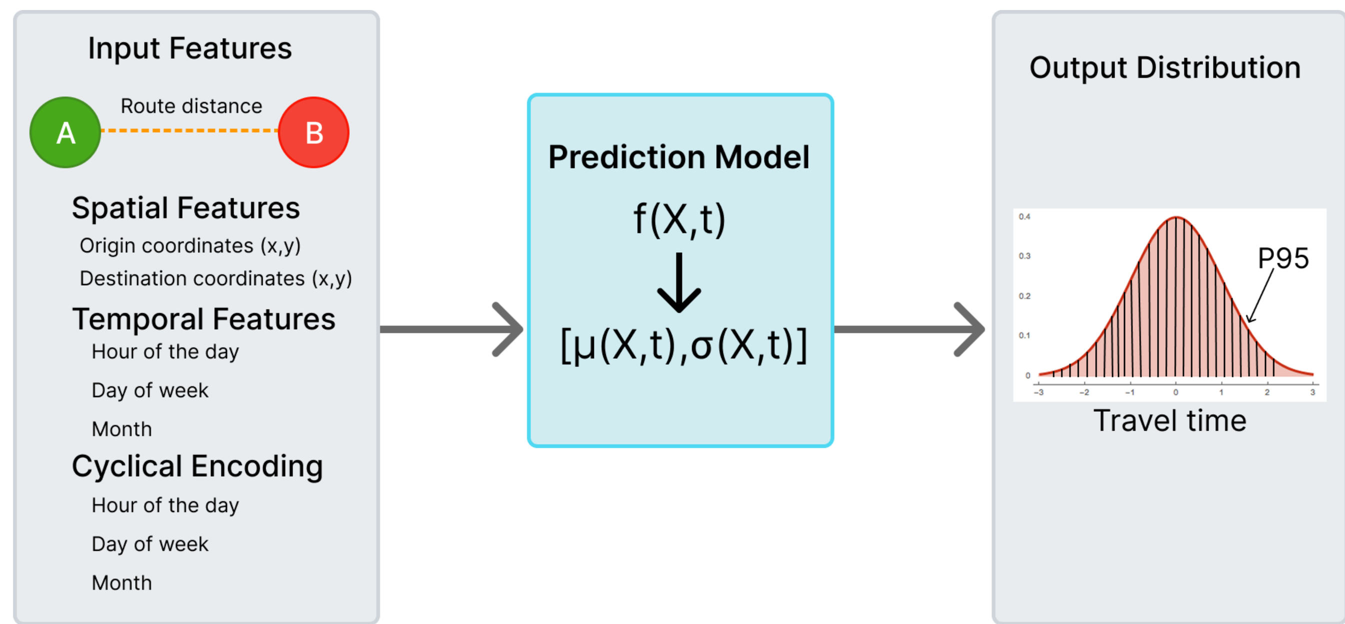

Figure 3. Probabilistic Estimation of Travel Time Distributions.

Results

I. Accessibility evaluation

❑ Integrating DRT with CPT significantly increases accessibility, especially in low-density and poorly served areas.

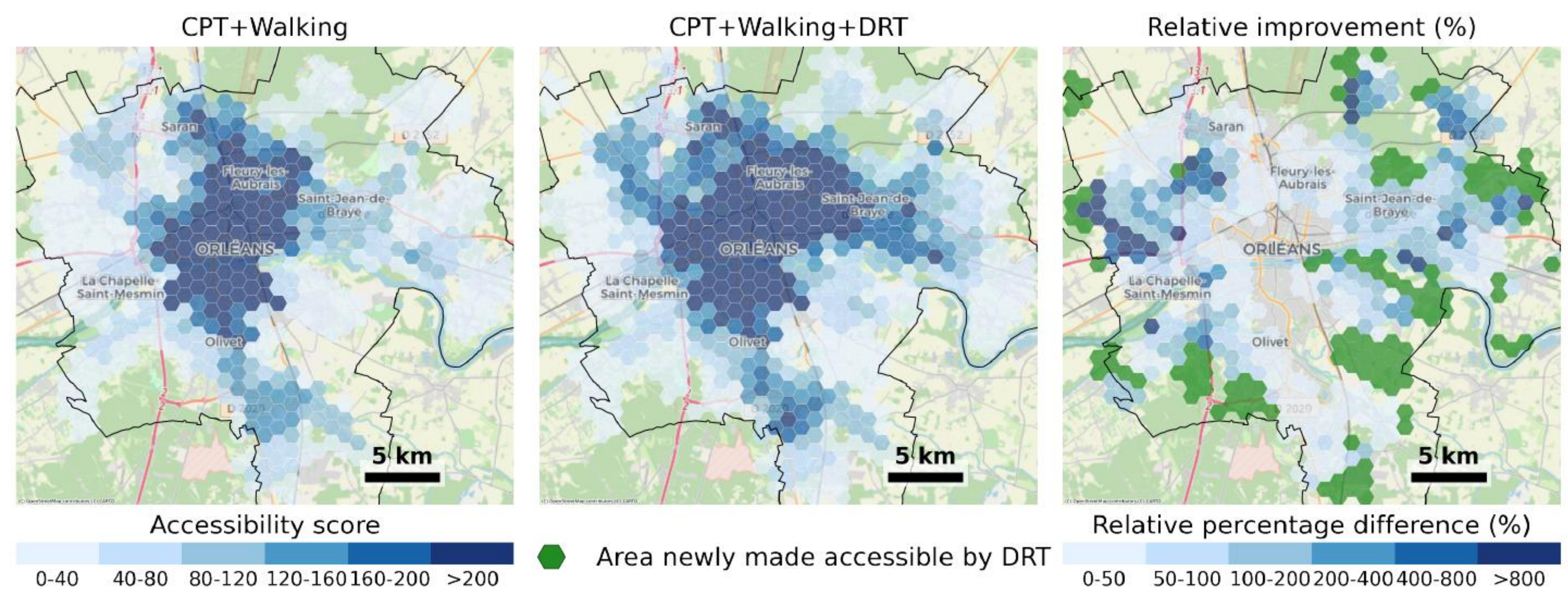

Figure 4. Accessibility scores and relative percentage improvement.

II. Equity evaluation

❑ Integrating DRT with CPT reduces accessibility inequality, as shown by lower Gini coefficients and improved Lorenz curves.

❑ Accessibility gains are more evenly distributed, particularly benefiting populations in previously underserved areas.

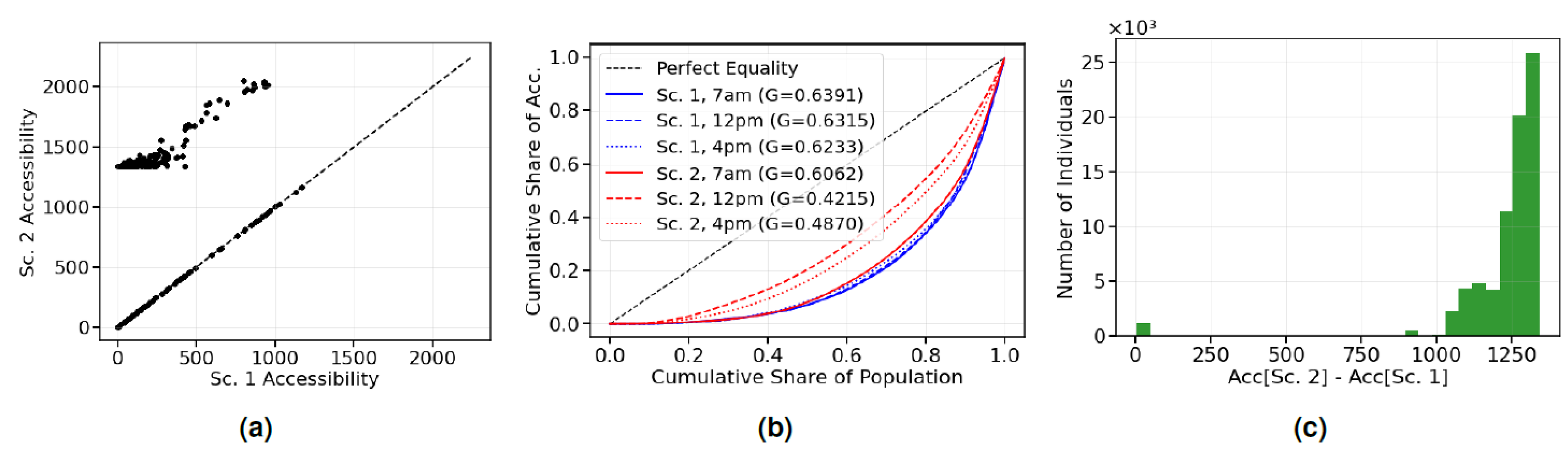

Figure 5. Accessibility Analysis: CPT+Walking (Sc. 1) vs CPT+Walking+DRT (Sc. 2): (a) Comparison, (b) Lorenz curves and Gini indeces, (c) Improvements

Conclusion

❑ This work introduces a data-driven framework to reliably compute accessibility in Demand-Responsive Transport by capturing travel time uncertainty.

❑ Results show that integrating DRT with CPT significantly increases accessibility and reduces inequality, particularly in underserved areas, supporting more informed and equitable transport planning.

References

[1] Miller, E. J. (2020). Measuring accessibility: Methods and issues. International Transport Forum.

[2] BIAZZO, I. et al. General scores for accessibility and inequality measures in urban areas. Royal Society Open Science.

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